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TEST PROGRAM.

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by

Ralph A. Bradley, Thomas C. Redman and
Thomas A. Gleeson

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The Florida State University
Department of Statistics
Tallahassee, Florida 32306

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AN EXAMINATION OF THE EFFECTS OF CLOUD SEEDING
IN PHASE II OF THE SANTA BARBARA CONVECTIVE BAND
SEEDING TEST PROGRAM

Ralph A. Bradley, Thomas C. Redman and Thomas A. Gleeson

Florida State University
Tallahassee, Florida

SUMMARY

This report covers statistical analyses of the experimental data from Phase II of the Santa Barbara Convective Band Seeding Test Program conducted from 1970 to 1974. Comparisons are made with earlier analyses of the Phase I data.

The Phase II study was in two parts, essentially separate experiments, one using ground-seeding techniques and one using aerial-seeding techniques. Data summaries of both precipitation responses and potential concomitant variables are given in an appendix. The main analyses for examination of the effects of seeding are weighted analyses of variance of transformed precipitation data for various defined target areas in Section 5. The experiments are relatively small and no effects of seeding are apparent except for the aerial-seeded part of the experiment, when border-line one-sided significances are obtained after omission of four storms, not treated fully in accordance with the design plan. The use of concomitant variables as covariates in covariance analyses is examined, with tables given in the appendix. The use of covariates enhanced apparent treatment effects for the ground-seeded part of the experiment but not for the aerial-seeded part.

The Phase II study used storms as the basic experimental unit whereas the Phase I study used the convective band. Difficulties arise in analyses because of this change. The covariates were again measured in the area of expected response from seeding and hence are suspect. Improved design of future similar studies would require use of better covariates, avoidance of possible seeding effects on the covariates, choice of good control areas, better selection of acceptable experimental units, the use of convective bands as experimental units, if possible persistence effects can be discounted, and the use of experimental designs that allow for storm effects as a source of variation.

1. INTRODUCTION

The Santa Barbara Convective Band Seeding Test Program was conducted by North American Weather Consultants and its affiliated organization, Aerometric Research Inc., from 1967 through 1974. The test program was in two phases, Phase I involving the 1967-68 through 1970-71 seasons of winter storms, and Phase II involving the 1971-72 through 1973-74 seasons with some preliminary data from the 1970-71 season. Research was sponsored on two concurrent projects by the Naval Weapons Center, China Lake, California and the Bureau of Reclamation, Denver, Colorado, the second study based on an augmented network of raingages. Basically, the studies involved cloud seeding of convective bands within winter storms in the Santa Barbara area of California, with precipitation responses attributable to these convective bands recorded by extensive networks of raingages. Two final reports were issued, Thompson, Brown and Elliott (1975) and Brown, Thompson and Elliott (1975), both of which have extensive bibliographies, including interim reports and publications associated with the projects.

Research sponsored by the Office of Naval Research at the Florida State University was motivated by the availability of the extensive data available from the test program, a perceived need for further statistical analysis, and perhaps the potential economic importance of effective cloud seeding of West Coast winter storms. Methods of analysis initially used are described in the two cited final reports and summarized also by Bradley, Srivastava and Lanzdorf (1977a), and, in less detail, by Bradley and Scott (1980). The original statistical analyses were based on application of the Wilcoxon-Mann-Whitney, two-sample, rank test, separately for the data from each raingage. Both precipitation measurements and ratios of precipitations at the raingage divided by average corresponding control area precipitations were

used with similar results for ground-seeded convective bands. For aerial-seeded bands in the Phase II study, no control area was used and analyses were based on the raingage precipitations. Extensive new analyses of the Phase I data, many of them exploratory in nature, have been conducted under the present contract.

Our studies of the Phase I data have been extensive. It was desired to develop a procedure for data summarization of precipitation attributable to a convective band, the experimental unit of the Phase I experiment, for a designated target area. A response surface method was used; it was found necessary to represent response with a cubic surface. An integrated precipitation response was developed, but found to be very highly correlated with the simple precipitation mean, the latter then being considered as the adequate measure of precipitation for a target or control area. Efforts on data summarization have been reported by Bradley, Srivastava and Lanzdorf (1977a, 1977b). Gleeson (1977) summarized data on possible covariates associated with each convective band, covariates that were based both on cloud physics measurements taken by radiosonde and band passage time or duration. Bradley, Srivastava and Lanzdorf (1979a,b) presented analyses of variance and covariance of band precipitation means and integrated precipitations for various target areas using those covariates along with precipitation measures of a defined control area. It was found that the standard deviation of precipitations among raingages in a target area was related linearly to the precipitation mean; this suggested analysis of transformed precipitations, $z = \log(\Delta+y)$, where y is precipitation at a raingage, z is the transformed response, and Δ is a constant associated with a target area, estimated from the observed linear relationship. The transformation was shown to effectively stabilize variances, except perhaps at very low precipitation levels. Analyses of variance and covariance were done with the transformed precipitations also. Bradley and Scott (1979, 1980), concerned with the validity of parametric assumptions, sampled the randomization distributions associated with certain of the analyses and verified that

parametric analyses approximated the randomization tests well. One finding was that use of the covariates was suspect, the covariates apparently having been affected by treatment (seeding); indeed, the cloud physics covariates were measured at Santa Barbara Airport, well into the intended area of expected response to seeding, and this must be judged a defect in the experimental design. Simple analyses of variance for defined target areas yielded one-sided significance levels of approximately 0.06 for the transformed data, consistent with a randomization analysis check by Elliott and Brown (1971). Scott (1979) used principal components for data summarization with limited success and difficulties in application. His first component was highly correlated with the precipitation mean and, although two additional components could be identified and interpreted, they contributed little in explanation of variability among raingages in a target or control area.

In this report, the more promising of the methods of analysis used for the Phase I data are applied in analysis of the Phase II data. If one viewed the Phase II experiment as a confirmatory one to verify the preliminary suggestions of an effect of cloud seeding exhibited by the Phase I experiment, we would regard the appropriate analyses to be those reported in Table IV below. But we report also analyses of covariance that provide conflicting impressions of the appropriateness of the use of the selected covariates. There were design changes for the Phase II experiment and these design changes detract from the experiment as a confirmatory one. There are anomalies in the data that may suggest the need for more care in the acceptance of a convective band as an experimental unit.

In Section 2 of this report, design changes in the experiment are highlighted and discussed. Section 3 describes the data summarization used, while Section 4 explains the methods of analysis. Analyses of variance for the effect of seeding are given and discussed in Section 5, together with discussion of analyses of covariance exhibited in Appendix tables. The report concludes with discussion and remarks on the experimentation and some comments on the improved design of future similar experiments.

2. PHASE II DESIGN CHANGES

Phase I and Phase II of the Santa Barbara Convective Band Seeding Test Program were designed very similarly. Both phases involved cloud seeding of convective bands, measurement of precipitation by essentially the same network of raingages, and measurement of cloud physics covariates by radiosonde, if possible at Santa Barbara Airport at Goleta, California. Raingage locations for the Naval Weapons Center study are given in Figure 2-4 by Thompson, Brown and Elliott (1975) and for the Bureau of Reclamation Study in Figure 2-4 by Brown, Thompson and Elliott (1975). Comparison of these figures shows the extended area and augmented network of raingages for the second study. But there were design changes for the Phase II study, some of them crucial to appropriate statistical analysis. We note the most important of the design changes, while assuming that the reader is familiar with the general Phase I experiment from analyses that we have reported earlier and may turn to the cited final reports if detail is required.

A decision to investigate the effects of aerial seeding in the Phase II experiment was made. The result was that the data for the Phase II experiment should be considered in two parts, aerial-seeded and ground-seeded, and this is done in this report. Ground-seeded data, seeding done from the same seeding site as in the Phase I experiment, resulted when aerial seeding was not possible. A randomized decision to seed or not seed was applied and the ground-seeded data consist of responses to both seeded and not-seeded convective bands as they did in the Phase I data. The aerial-seeded data are similar to the ground-seeded data, with responses to both seeded and not-seeded convective bands. The seeding aircraft flew its designated flight paths in both situations but performed cloud-seeding only on the appropriate randomized decision. The seeding aircraft flew at or near the freezing level along a 30 to 60 km track within the convective band and transverse to its direction of movement. This was done in an area 10 to 30 km west of the coast, upwind of the

centroid of the instrumented area. Ground-seeded data resulted when range scheduling conflicts or other problems made aerial-seeding impractical; the path of the seeding aircraft was in restricted air space associated with Vandenberg Air Force Base. Tables in this report are labelled (a) or (b) for ground-seeded and aerial-seeded data summaries respectively.

The silver iodide seeding generator was changed for the Phase II experimentation, with a new generator developed by North American Weather Consultants. Some changes in concentration of the $AgI-NH_4I$-accetone solution were made for the 1972-73 and 1973-74 seasons. A ground-based version of the airborne acetone burner was employed when ground seeding was necessary. During the 1972-73 season, two of the seeding flights utilized droppable WMU-1/8 pyrotechnic flares. Aerial-seeded data sets used in this report and in analyses in the two final reports of the experimenters contain all aerial-seeded convective bands. In the Phase I experimentation and in the ground-seeded, Phase II experimentation, precipitation measurements west of the ground-seeding site may be and have been used to provide a covariate, control-area precipitation, in certain covariance analyses. This is not possible for the aerial-seeded experimentation. Indeed, for analyses of the aerial-seeded data, target areas may be defined that includes raingages regarded to be in the control area for the ground-seeded data.

The major design change affecting appropriate statistical analysis was that a storm became the experimental unit rather than the convective band. We find the stated reason somewhat obscure and quote from Thompson, Brown and Elliott (1975):

> "One criticism of the band-by-band randomization scheme employed in the preceding phase of the program was that, although it did provide adequately for the possibility of interactive effects between a seeded band and unseeded bands preceding or following it within a given storm, it did not permit the testing for any multiplication effects which might occur if all bands within a given frontal zone were seeded.

To meet this objection, a randomization mode, based upon a rigid 48-hour time block, was adopted in which, during the 48-hour period subsequent to the onset of precipitation, each convective band was treated in accordance with the randomized decision for the block as a whole. Since storms in this area have typical durations of between twelve and thirty-six hours, this provided effective randomization on a storm-by-storm basis, while retaining the advantage of large sample size provided by statistical treatment of rainfall data for individual bands."

We are not sure of the interpretation of "multiplication effect" in the quotation. It would appear to relate to a build-up effect of seeding as the storm progresses and the several convective bands pass over a target area. But this implies a carry-over effect from seeding one band to successive bands in a storm sequence of bands. If this occurs, it seems likely to occur as a carry-over effect on a subsequent unseeded band also and we cannot reconcile this with the earlier statement that provision was made for "the possibility of interactive effects". Bradley, Srivastava and Lanzdorf (1979a) looked for carry-over effects on unseeded bands following seeded bands in the same storm and also for effects due to positions of the band in the storm without success - see Tables SA-V to SA-IX. No analyses are given in the two final reports of the experimenters for the detection of a multiplication effect. Indeed, analyses given in these two final reports for the Phase II data parallel those used for the Phase I data, are again on a raingage-by-raingage basis, and take no cognizance of the fact that a storm has now become the experimental unit, contrary to implications of the last sentence of the quotation.

We shall designate the variability among convective bands treated alike within storms as a sampling error. This is appropriate if there are no positional or multiplication effects. We shall designate the variability among storms treated alike, seeded or not seeded, as an experimental error. If there is a component of variability in this experimental error attributable to variation among storms, we would expect that the experimental error would be larger than the sampling error. But variability between treatments, seeded and not seeded, must contain also between-storm variability and sampling variability, along with a possible effect of treatment. In an analysis of variance or covariance table, mean squares for sampling error, experimental error, and treatment must be properly calculated. The appropriate test for treatment or seeding effect must take into account both within-storm band to band variability and between-storm variability.

As in the Phase I experiment, covariates were observed for each convective band. When the experimental unit is the storm, this produces a somewhat unusual analysis. The covariates must be used to "standardize" the sampling unit (convective band) responses; thus it would be expected that the use of covariates would reduce sampling error. They may be expected also to affect mean squares for experimental error and treatment, since these mean squares have expectations with a component of variability for sampling error. If covariates are correlated with treatment, the problem encountered in the Phase I covariance analyses, their use may again remove whatever treatment effect is present.

Our methods of analysis are described in Section 4. It will be seen that they provide means of calculation of mean squares for sampling error and experimental error. The raingage-by-raingage, Wilcoxon-Mann-Whitney rank tests of the experimenters' reports are designed to detect location changes in the distributions of seeded and non-seeded responses and assume, under the hypothesis tested, that seeded and non-seeded responses come from a single response distribution. This is not the case if storm effects are present.

3. PHASE II DATA SUMMARIZATION

Throughout Phase II data summarization and analysis, the ground-seeded and aerial-seeded data are considered separately. Given that storms are experimental units, the tabulation of storms seeded and not seeded is as follows:

No. of Storms	Seeded	Not Seeded	Total
Gd. Seeded Part	7	5	12
Aerial Seeded Part	12	18	30

Similarly, on a convective band basis, the tabulation is:

No. of Bands	Seeded	Not Seeded	Total
Gd. Seeded Part	20	10	30
Aerial Seeded Part	18	27	45

Some notes are in order. A storm and its convective bands became part of the ground-seeded or aerial-seeded experimentation because of the impracticality or practicality of aerial seeding; the randomized decision on whether or not to seed came later. Thus the ground-seeded part of the experimentation included both seeded and not-seeded storms as did the aerial-seeded part of the experiment. In addition, there were four storms that were part of the aerial-seeded data with some bands seeded and some bands not-seeded - see Table A.1(b), storms 91, 92, 3 and 12. In the table above and in some analyses, each of these storms was treated as two storms, one-seeded and one not-seeded.

The precipitation data are summarized in Tables A-1(a) and A-1(b) of the appendix by storms, bands and response areas. For each convective band in each storm for each response area, the mean precipitation in inches is given along with the number

of operative raingages in the response area and the variance among those raingages. The response areas are defined in Table I, the first five of which were used also in our Phase I data analyses. Response area (i) is the main target area for ground-seeded experimentation. Areas (ii) and (iii) are respectively near and far from the ground seeding site and are used to investigate areas of effect of ground seeding. Area (v) is a control area west and up-wind of the seeding site for ground-seeded experimentation; but becomes a near to seeding target area for aerial seeding. Area (vi) is a total target area for aerial seeding. Data summaries for response areas (i) - (vi) are based on the augmented network of raingages used in the Bureau of Reclamation study. Areas (vii) and (viii) are control and target areas for the Naval Weapons Center Study for ground-seeded data, while both, along with Area (ix) are target areas for aerial-seeded data. Data summaries and analyses for Areas (vii) - (ix) are based on the raingage network of the Naval Weapons Center Study. The numbers of stations in Table I are the numbers of raingages in the response areas, not all of which were always operative. Reference to Figures 2-4 of the two final reports will assist in understanding the defined response areas. Tables A-1(a) and A-1(b) do not have data for response area (ix), but such data may be reconstructed from those for Areas (vii) and (viii) if desired.

TABLE I

Definitions of Response Areas*

Response Area	Ranges in Degrees Latitude	Longitude	Number of Stations
(i)	34.0 - 35.25	118.0 - 120.02	106
(ii)	34.4 - 35.0	119.51 - 120.02	25
(iii)	34.0 - 35.0	118.0 - 119.51	71
(iv)	Areas (ii) + (iii)		96
(v)	34.4 - 35.25	120.02 - 120.60	34
(vi)	Areas (i) + (v)		140
(vii)	All stations in Naval Weapons Center Study West of seeding site at 120.02^{o} long.		41
(viii)	All stations in Naval Weapons Center Study East of seeding site at 120.02^{o} long.		63
(ix)	Stations and Areas of (vii) + (viii)		104

*Areas (i) - (iv) correspond with areas defined for reports on the Phase I data; definitions must be checked for other areas for comparisons.

Precipitation means in inches for the various response areas are given in Tables II(a) and II(b) respectively for ground-seeded and aerial-seeded bands. We have exhibited these means for visual comparisons of seeded and not-seeded results, since our analyses are based on transformed precipitations for which means are less easily interpreted.

Examination of Table A-1(a) shows that not-seeded storm 4 with one band has extremely high precipitation. We have treated it as an outlier and performed analyses with this storm included and excluded. The first section of Table II(a) gives means for all ground-seeded bands while the second section omits this storm and band. It is seen that the omission of the extreme storm has a major effect on the apparent effect of seeding. Indeed, further examination of Table A-1(a) suggests that non-seeded band 9-1 has high precipitation; while seeded bands 8-2 and 22-3 have somewhat high precipitations. These notes reflect the high variability of cloud seeding data; in this small ground-seeded experiment, the "luck of the draw" in the randomization may play an important role. From another viewpoint, this variation may suggest need for better criteria for determination of a "seedable" band. Table II(b) is in two parts, the first with all storms and bands and the second with the four mixed storms discussed above omitted. It happened that, for all four storms, the unseeded bands had higher precipitation means than the seeded bands. We do not like the removal of data without assignable cause and tend to put most weight on analyses with all of the available data used. The means in Tables II(a) and II(b) are simple means of the convective band means of Tables A-1(a) or Tables A-1(b) as appropriate.

TABLE II(a)

Precipitation Means in Inches for the Various Response Areas
Ground-Seeded Bands

Response Areas	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)
All Bands								
Seeded Bands	0.241	0.308	0.233	0.252	0.250	0.243	0.254	0.251
Unseeded Bands	0.309	0.450	0.279	0.321	0.371	0.324	0.359	0.346
Extreme Storm Omitted								
Seeded Bands	0.241	0.308	0.233	0.252	0.250	0.243	0.254	0.251
Unseeded Bands	0.196	0.297	0.170	0.202	0.247	0.208	0.243	0.230

TABLE II(b)

Precipitation Means in Inches for the Various Response Areas
Aerial-Seeded Bands

Response Areas	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)	(ix)
Part 1 - All bands*									
Seeded Bands	0.275	0.363	0.265	0.290	0.324	0.287	0.335	0.288	0.307
Unseeded Bands	0.217	0.253	0.220	0.228	0.225	0.219	0.242	0.210	0.223
Part 2 - Mixed Storms Omitted									
Seeded Bands	0.369	0.484	0.357	0.388	0.432	0.384	0.444	0.383	0.408
Unseeded Bands	0.217	0.264	0.216	0.228	0.238	0.222	0.254	0.215	0.231

*Four storms had both seeded and unseeded bands. In Part 1, seeded and unseeded bands in sequences were treated as different storms; in Part 2, these storms were omitted. See text.

For analyses of variance and covariance, as in the Phase I analyses of Bradley, Srivastava and Lanzdorf (1979a, b), it seems appropriate to transform the data to stabilize variances. This was done by plotting the standard deviation among raingage observations for a band and response area against the corresponding mean response, the data being available from Tables A-1(a) and A-1(b). It is found that these plots are very nearly linear. Straight lines were fitted by least squares and slopes and intercepts, B and A, were estimated. The transformation was $z = \log(\Delta+y)$ where y is precipitation at a raingage and $\Delta = A/B$. This procedure was illustrated for Phase I data in Figures 4 and 5 of Bradley, Srivastava and Lanzdorf (1979b). Figures for the various target areas for ground-seeded and aerial-seeded data for Phase II were very similar. The transformation does stabilize variances, except perhaps for very small values of y. Values of Δ are given in Tables III(a) and III(b). Ground-seeded values in Table III(a) are slightly larger than those found in the Phase I analyses, the latter ranging from 0.03 to 0.075. The basic data summarization of precipitation data in preparation for analyses of variance and covariance involves preparation of tables like Tables A-1(a) and A-1(b) giving means of the transformed raingage precipitations by storms and bands for the various response areas. It was a secondary effect of the use of the transformation that the influence of larger precipitation bands was somewhat reduced; weighted means of transformed data were such that the means of seeded bands were larger than means of not-seeded bands for all but one of the target areas - see the signs in Tables IV(a) and IV(b) in Section 5.

TABLE III(a)

Values of Δ for Ground-Seeded Data by Target Areas
Transformation $z = \log(\Delta + y)$, y is Raingage Precipitation

Target Areas	(i)	(ii)	(iii)	(iv)	(v)
Δ	0.11172	0.03887	0.15562	0.11160	0.07284
	(0.09804)*	(0.04558)	(0.12958)	(0.09602)	(0.06702)

*Values in parentheses obtained when one extreme precipitation storm, Storm 4 with one band, not-seeded, has been omitted.

TABLE III(b)

Values* of Δ for Aerial-Seeded Data by Target Areas
Transformation $z = \log(\Delta + y)$, y is Raingage Precipitation

Target Areas	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(vii)	(ix)
Δ	0.03979	0.03244	0.05372	0.04280	0.07939	0.05545	0.09646	0.02398	0.05958

*Values given are for Part 1, use of all bands; the transformation was not changed when mixed storms were omitted.

Gleeson (1977) defined and summarized data on concomitant variables or covariates for the Phase I data. Similar data summaries are provided in Tables A-2(a) and A-2(b) of the appendix of this report for the Phase II data. Table notes on these tables are given also in the Appendix, providing explanations of these concomitant variables. Covariates considered are listed in order below with brief descriptive labels, their designations matching those used in the Phase I reports:

X_1: Mixing Ratio,
X_2: 700 mb Wind Speed,
X_3: 700 mb Wind Direction,
X_4: Mean Wind Speed,
X_5: Direction, Avg. Vector Wind,
X_6: 500 mb Temperature, (3.1)
X_7: Stability Class,
X_8: Showalter Index,
X_9: Stability Wind Speed,
X_{10}: Direction, Stability Wind,
X_{11}: Instability Transport,
X_{12}: Band Passage Time (Seeding Site), Duration.

The data in Tables A-2(a) and A-2(b) are used with the band means of the transformed precipitation data for response area (i) to exhibit correlations in Tables A-3(a) and A-3(b) for Area (i). In Table A-3(a), X_c and Z appear also. X_c is the precipitation mean by bands for response area (v), the control area for ground seeding, the means based on the Bureau of Reclamation data. Z is the seeding indicator variable. These tables are given for comparison with Table A-1 of Bradley, Srivastava

and Lanzdorf (1979a). The patterns of correlations are very similar, perhaps somewhat larger in magnitude for Phase II data. Two correlations merit comment. The correlations between transformed precipitation band mean and X_c, control area precipitation, are larger, changing from 0.7 to 0.9. The correlations between transformed precipitation band mean and X_{12}, band passage time or duration, are smaller, particularly for the aerial-seeded data.

Detailed analyses of the Phase I data showed redundancies in the covariates. It was judged that the set of covariates could be reduced to X_2, X_3, X_6, X_7, X_8, and X_{11} along with consideration of X_c and X_{12}. This is done again in this report in the covariance analyses. We shall regard the first six covariates as the basic set. Models considered in analyses of variance and covariance, differently labelled than in Phase I analyses, are as follows:

Model	Identification of Covariates	
(1)	No covariates	
(2)	X_2, X_3, X_6, X_7, X_8, X_{11}	
(3)	Covariates of (2) plus X_{12}	(3.2)
(4)	Covariates of (2) plus X_c.	
(5)	Covariates of (2) plus X_{12}, X_c.	

Description of data summarization for analyses reported in subsequent sections of this report is now complete. The methods of analysis are described in the following section.

4. METHODS OF STATISTICAL ANALYSIS

Bradley, Srivastava and Lanzdorf (1979a,b) developed analyses of variance and covariance by target areas for transformed precipitations and covariate values using the convective band as the experimental unit. Since the storm has become the experimental unit in the Phase II experimentation, changes in the methods of analysis are necessary and our new methods are explained below.

Consider first the analysis of variance. The basic linear model is

$$z_{ij\alpha} = \mu + \tau_i + \beta_{j(i)} + \varepsilon_{ij\alpha}, \tag{4.1}$$

where $z_{ij\alpha}$ is the mean of the transformed precipitations at raingages in a target area for band α of storm j receiving treatment i, $\alpha = 1,\ldots,n_{ij}$, n_{ij} being the number of bands in storm j with treatment i, $j = 1,\ldots,n_i$, n_i being the number of storms receiving treatment i, and $i = 1,2$, for seeded and not seeded storms respectively. The components of the model in the right-hand side of (4.1) are μ, the general mean, τ_i, the effect of treatment i, $\beta_{j(i)}$, the effect of storm j of treatment i taken as a member of a set of independent random variables with zero means and variances σ^2, and $\varepsilon_{ij\alpha}$, a member of a second set of independent random variables, independent of the first set, with zero means and variances $\sigma_s^2/m_{ij\alpha}$, where $m_{ij\alpha}$ is the number of raingages contributing to $z_{ij\alpha}$.

Transformation of raingage precipitations was effected to stabilize variances, permitting the assumption that the variance of $\varepsilon_{ij\alpha}$ is proportional to $\sigma_s^2/m_{ij\alpha}$, since $z_{ij\alpha}$ is the mean of $m_{ij\alpha}$ transformed raingage precipitations. The variance of $\varepsilon_{ij\alpha}$ would be $\sigma_s^2/m_{ij\alpha}$, if each transformed raingage precipitation had variance

σ_s^2 and such precipitations in a target area for a convective band were independent; we believe that the proportionality assumption is adequate. To develop the analysis of variance table for the model (4.1), it is necessary to use weighted least squares in minimization of

$$\sum_{i=1}^{2} \sum_{j=1}^{n_i} \sum_{\alpha=1}^{n_{ij}} m_{ij\alpha}(z_{ij\alpha} - \mu - \tau_i - \beta_{j(i)})^2 \tag{4.2}$$

There is a redundancy of treatment parameters and it is convenient to add the constraint that $\sum_{i=1}^{2} m_{i..}\tau_i = 0$ and to minimize (4.2) subject to this constraint. The number of raingage observations contributing to estimation of the mean of the transformed precipitations for treatment i is $m_{i..}$. The analysis of variance table resulting is as follows:

Source of Variation	d.f.	S.S.	Expected M.S.
Treatment	1	$\sum_{i=1}^{2} m_{i..}(\bar{z}_{i..}-\bar{z}_{...})^2$	$\sigma_s^2+k_2\sigma^2+\sum_{i=1}^{2} m_{i..}\tau_i^2$
Experimental Error	n_1+n_2-2	$\sum_{i=1}^{2} \sum_{j=1}^{n_i} m_{ij.}(\bar{z}_{ij.}-\bar{z}_{...})^2$	$\sigma_s^2+k_1\sigma^2$
Subtotal	n_1+n_2-1	$\sum_{i=1}^{2} \sum_{j=1}^{n_i} m_{ij.}(\bar{z}_{ij.}-\bar{z}_{...})^2$	-
Sampling Error	$\sum_{i=1}^{2} \sum_{j=1}^{n_i}(n_{ij}-1)$	$\sum_{i=1}^{2} \sum_{j=1}^{n_i} \sum_{\alpha=1}^{n_{ij}} m_{ij\alpha}(z_{ij\alpha}-\bar{z}_{ij.})^2$	σ_s^2
Total	$\sum_{i=1}^{2} \sum_{j=1}^{n_i} n_{ij} - 1$	$\sum_{i=1}^{2} \sum_{j=1}^{n_i} \sum_{\alpha=1}^{n_{ij}} m_{ij\alpha}(z_{ij\alpha}-\bar{z}_{...})^2$	-

(4.3)

Some symbols in (4.3) require definition:

$$m_{...} = \sum_{i=1}^{2} \sum_{j=1}^{n_i} \sum_{\alpha=1}^{n_{ij}} m_{ij\alpha},$$

$$m_{ij.} = \sum_{\alpha=1}^{n_{ij}} m_{ij\alpha},\ m_{i..} = \sum_{j=1}^{n_i} \sum_{\alpha=1}^{n_{ij}} m_{ij\alpha},\ \bar{z}_{ij.} = \sum_{\alpha=1}^{n_{ij}} m_{ij\alpha} z_{ij\alpha}/m_{ij.},$$

$$\bar{z}_{i..} = \sum_{j=1}^{n_i} \sum_{\alpha=1}^{n_{ij}} m_{ij\alpha} z_{ij\alpha}/m_{i..},\ \bar{z}_{...} = \sum_{i=1}^{2} \sum_{j=1}^{n_i} \sum_{\alpha=1}^{n_{ij}} m_{ij\alpha} z_{ij\alpha}/m_{...},$$

$$k_1 = (m_{...} - \sum_{i=1}^{2} \frac{1}{m_{i..}} \sum_{j=1}^{n_i} m_{ij.}^2)/(n_1+n_2-2),$$

and (4.4)

$$k_2 = \sum_{i=1}^{2} \left[\frac{1}{m_{i..}} - \frac{1}{m_{...}}\right] \sum_{j=1}^{n_i} m_{ij.}^2 .$$

An immediate problem is seen with (4.3) in view of (4.4). To test for treatment or seeding effect, we need $k_1 = k_2$. If the experiment were balanced so that $m_{ij\alpha} = m$, for all i, j and α, and $n_{ij} = n$ for all i,j, then $k_1 = k_2 = mn$. If the assumption in the model were changed so that it is assumed that $V(\beta_{j(i)}) = \sigma^2/m_{ij.}$, then $k_1 = k_2 = 1$. This change does not seem appropriate.

The problem is that, because of the lack of balance in the experiment, the effects of storms and treatment are somewhat confounded. We have demonstrated a defect in the design of the Phase II experiment, one that is implicit in any analysis, including the raingage-by-raingage analyses of the investigators' final reports. It remains to investigate the extent of the difficulty and this is done in the following section.

Covariate analyses are given in Tables A-4(a) and A-4(b) of the appendix for the ground-seeded and aerial-seeded data respectively. General linear regression methods were used to develop the analysis of covariance tables. Model (4.1) was modified to include covariates $X_1,\ldots,X_p$ with values $x_{1ij\alpha},\ldots,x_{pij\alpha}$ for band α of storm j with treatment i. It was necessary to introduce design parameters also to represent the n_1+n_2-2 parameters for storm contrasts within treatments and these may be designated W_{ik} with value w_{ikj} for a band in storm j and treatment i, $k = 1,\ldots(n_i-1)$. Values of w_{ikj} were taken proportional the elements of a generalized Helmert matrix:

$$w_{ikj} = m_{i(k+1).} \ , \ j = 1,\ldots,k,$$

$$= -\sum_{j'=1}^{k} m_{ij'.} \ , \ j = (k+1),$$

$$= 0 \ , \ j = (k+2),\ldots,n_i.$$

The model corresponding to (4.1) is now

$$z_{ij\alpha} = \mu + \tau Z_i + \sum_{k=1}^{n_i-1} w_{ikj}\beta_k + \sum_{\gamma=1}^{p} \Gamma_\gamma x_{\gamma ij\alpha} + \varepsilon_{ij\alpha}. \qquad (4.5)$$

In (4.5), Γ_γ is the regression coefficient for the covariate X_γ, $\gamma = 1,\ldots,p$, τ is the regression coefficient for the seeding indicator variable Z_i, $Z_i = 1$ if seeded, $i = 1$, and -0 if not seeded, $i = 2$, and the β_k are linear functions of the $\beta_{j(i)}$ of (4.1).

Weighted regression is employed and the sum of squares to be minimized is

$$\sum_{i=1}^{2} \sum_{j=1}^{n_i} \sum_{\alpha=1}^{n_{ij}} m_{ij\alpha}(z_{ij\alpha}-\mu-\tau Z_i - \sum_{k=1}^{n_i-1} \beta_k w_{ikj} - \sum_{\gamma=1}^{p} \Gamma_\gamma x_{\gamma ij\alpha})^2. \tag{4.6}$$

The analysis of covariance table is developed through introducing terms in the model (4.5) in the appropriate sequence and use of the corresponding minimum sums of squares from (4.6). Let the reduced models building to (4.5) depend on subsets of the model parameters as shown in (4.7) with the terms in the right-hand side of (4.5) numbered in order, and let the corresponding minimum weighted sums of squares be also designated as indicated in the final column of (4.7):

Model	Terms	Sums of Squares	
A	1	SS(A)	
B	1,4	SS(B)	
C	1,2,3,4	SS(C)	(4.7)
D	1,3,4	SS(D)	

The analysis of covariance table is obtained from the indicated sums of squares:

Source of Variation	d.f.	S.S.	
Treatment	1	SS(D)-SS(C)	
Experimental Error	n_1+n_2-2	SS(B)-SS(D)	
Subtotal	n_1+n_2-1	SS(B)-SS(C)	(4.8)
Covariates	p	SS(A)-SS(B)	
Sampling Error	$\left[\sum_{i=1}^{2} \sum_{j=1}^{n_i} (n_{ij}-1)\right]-p$	SS(C)	
Total	$\sum_{i=1}^{2} \sum_{j=1}^{n_i} n_{ij} \; -1$	SS(A)	

The analysis of covariance is subject to the same confounding of storm effects and treatment effects as discussed above in regard to the analysis of variance.

If the fourth term in the right-hand side of (4.5) is omitted, then the analysis of variance of (4.3) results from the weighted regression analysis.

5. ANALYSES OF VARIANCE AND COVARIANCE

Response areas (i) - (iv) and (viii) are target areas for the ground-seeded experimentation and areas (i) - (ix) are possible target areas for the aerial-seeded experimentation. Target areas (i) and (vi) represent total target areas for ground-and-aerial-seeded experimentation with the Bureau of Reclamation data and target areas (viii) and (ix) respectively for the Naval Weapons Center data. For the ground-seeded experimentation, response areas (v) and (vii) represent control areas and yield values of the covariate X_c, control area mean precipitation, for the Bureau of Reclamation data and the Naval Weapons Center data respectively. There are no control areas for the aerial-seeded experimentation.

Various models for analyses are given in (3.2). Model (1) corresponds with the model for the analysis of variance, (4.1). Models (2) - (5) yield analyses of covariance, see (4.5), with $p = 6, 7, 7,$ and 8 respectively. Table IV(a) gives the analysis of variance tables for target areas (i) - (iv) and (viii) based on band means of transformed target-area, raingage precipitations for all 30 bands and 12 storms of the ground-seeded experimentation. Table IV(a) Continued matches Table IV(a) except that Storm 4 with one-band, not-seeded has been omitted and the analyses are based on 29 bands and 11 storms - see Table II(a) and comments in Section 3. Table IV(b), Part 1, give the analysis of variance tables for target areas (i) - (ix) based on band means of transformed target-area, raingage precipitations for all 45 bands and 30 storms of the aerial-seeded experimentation.

TABLE IV(a)

Analyses of Variance (No Covariates) for the Various Target Areas, Transformed Data Ground-Seeded Bands

Target Area	Source of Variation	d.f.	Mean Squares	F-Ratio	Sign
(i)	Seeding	1	0.14	0.00	+
	Exp. Error	10	45.74	-	
	Subtotal	11	41.59	-	
	Sampl. Error	18	15.44	-	
(ii)	Seeding	1	2.08	0.10	+
	Exp. Error	10	21.00	-	
	Subtotal	11	19.28	-	
	Sampl. Error	18	5.70	-	
(iii)	Seeding	1	0.01	0.00	-
	Exp. Error	10	24.74	-	
	Subtotal	11	22.50	-	
	Sampl. Error	18	10.51	-	
(iv)	Seeding	1	0.12	0.00	+
	Exp. Error	10	42.81	-	
	Subtotal	11	38.93	-	
	Sampl. Error	18	15.69	-	
(viii)	Seeding	1	1.12	0.03	+
	Exp. Error	10	38.42	-	
	Subtotal	11	35.03	-	
	Sampl. Error	18	8.19	-	

TABLE IV(a) - Continued

Analyses of Variance (No Covariates) for
the Various Target Areas, Transformed Data
Ground-Seeded Bands, Extreme Storm Omitted*

Target Area	Source of Variation	d.f.	Mean Squares	F - Ratio	Sign
(i)	Seeding	1	20.73	0.71	+
	Exp. Error	9	29.16	-	
	Subtotal	10	28.32	-	
	Sampl. Error	18	16.96	-	
(ii)	Seeding	1	11.93	0.88	+
	Exp. Error	9	13.59	-	
	Subtotal	10	13.43	-	
	Sampl. Error	18	5.35	-	
(iii)	Seeding	1	9.85	0.61	+
	Exp. Error	9	16.16	-	
	Subtotal	10	15.73	-	
	Sampl. Error	18	12.28	-	
(iv)	Seeding	1	19.47	0.70	+
	Exp. Error	9	27.81	-	
	Subtotal	10	26.98	-	
	Sampl. Error	18	17.48	-	
(viii)	Seeding	1	21.11	0.82	+
	Exp. Error	9	25.77	-	
	Subtotal	10	25.30	-	
	Sampl. Error	18	8.58	-	

*One extreme precipitation storm, Storm 4 with one band, not seeded, has been omitted.

TABLE IV(b)

Analyses of Variance (No Covariates) for the Various Target Areas, Transformed Data Aerial-Seeded Bands, Part 1-All Bands

Target Area	Source of Variation	d.f.	Mean Squares	F - Ratio	Sign
(i)	Seeding	1	80.22	0.89	+
	Exp. Error	28	89.74	-	
	Subtotal	29	89.42	-	
	Sampl. Error	15	80.82	-	
(ii)	Seeding	1	31.35	1.27	+
	Exp. Error	28	24.78	-	
	Subtotal	29	25.01	-	
	Sampl. Error	15	26.44	-	
(iii)	Seeding	1	40.29	0.71	+
	Exp. Error	28	57.05	-	
	Subtotal	29	56.48	-	
	Sampl. Error	15	45.93	-	
(iv)	Seeding	1	76.16	0.90	+
	Exp. Error	28	84.91	-	
	Subtotal	29	84.61	-	
	Sampl. Error	15	75.11	-	
(v)	Seeding	1	23.40	1.51	+
	Exp. Error	28	15.50	-	
	Subtotal	29	15.77	-	
	Sampl. Error	15	15.55	-	

TABLE IV(b) - Continued

Analyses of Variance (No Covariates) for the Various Target Areas, Transformed Data Aerial-Seeded Bands, Part 1-All Bands

Target Area	Source of Variation	d.f.	Mean Squares	F-Ratio	Sign
(vi)	Seeding	1	87.09	0.98	+
	Exp. Error	28	88.85	-	
	Subtotal	29	88.79	-	
	Sampl. Error	15	82.76	-	
(vii)	Seeding	1	18.22	1.10	+
	Exp. Error	28	16.49	-	
	Subtotal	29	16.55	-	
	Sampl. Error	15	14.83	-	
(viii)	Seeding	1	80.86	1.38	+
	Exp. Error	28	58.77	-	
	Subtotal	29	59.53	-	
	Sampl. Error	15	63.50	-	
(ix)	Seeding	1	62.53	1.13	+
	Exp. Error	28	55.32	-	
	Subtotal	29	55.60	-	
	Sampl. Error	15	55.19	-	

TABLE IV(b) - Continued

Analyses of Variance (No Covariates) for
the Various Target Areas, Transformed Data
Aerial-Seeded Bands, Part 2-Mixed Storms Omitted

Target Area	Source of Variation	d.f.	Mean Squares	F - Ratio	Sign
(i)	Seeding	1	320.97	3.88*	+
	Exp. Error	20	82.73	-	
	Subtotal	21	94.07	-	
	Sampl. Error	13	89.57	-	
(ii)	Seeding	1	91.18	4.06*	+
	Exp. Error	20	22.45	-	
	Subtotal	21	25.73	-	
	Sampl. Error	13	29.21	-	
(iii)	Seeding	1	186.67	3.49*	+
	Exp. Error	20	53.56	-	
	Subtotal	21	59.86	-	
	Sampl. Error	13	51.10	-	
(iv)	Seeding	1	301.78	3.86*	+
	Exp. Error	20	78.18	-	
	Subtotal	21	88.82	-	
	Sampl. Error	13	83.21	-	
(v)	Seeding	1	63.47	4.44*	+
	Exp. Error	20	14.31	-	
	Subtotal	21	16.65	-	
	Sampl. Error	13	17.87	-	

*Values significant for one-sided test (positive difference in means) at .05 level of significance.

TABLE IV(b) - Continued

Analyses of Variance (No Covariates) for
the Various Target Areas, Transformed Data
Aerial-Seeded Bands, Part 2-Mixed Storms Omitted

Target Area	Source of Variation	d.f.	Mean Squares	F - Ratio	Sign
(vi)	Seeding	1	327.35]	4.02*	+
	Exp. Error	20	81.46	-	
	Subtotal	21	93.17	-	
	Sampl. Error	13	93.63	-	
(vii)	Seeding	1	54.98	3.56*	+
	Exp. Error	20	15.43	-	
	Subtotal	21	17.32	-	
	Sampl. Error	13	17.10	-	
(viii)	Seeding	1	232.07	4.25*	+
	Exp. Error	20	54.64	-	
	Subtotal	21	63.09	-	
	Sampl. Error	13	69.69	-	
(ix)	Seeding	1	196.49	3.84*	+
	Exp. Error	20	51.19	-	
	Subtotal	21	58.10	-	
	Sampl. Error	13	61.86	-	

*Values significant for one-sided test (positive difference in means) at .05 level of significance.

Table IV(b), Part 2, matches Table IV(b), Part 1, except that four storms, subdivided into separate seeded and not-seeded storms as described in Section 3, have been omitted. The final column in Tables IV(a) and IV(b) shows the sign of the difference in the mean of the transformed precipitations for seeded bands and not-seeded bands; it is interesting that the effect of transformation was to reverse the apparent negative effect of seeding exhibited in Table II(a), except for Target Area (iii), when all 30 bands and 12 storms are considered. The transformations reduce the contributions of extreme observations.

Analyses of covariance are given in Tables A-4(a), A-4(a) Continued, A-4(b), Part 1, and A-4(b), Part 2 for models (2) - (5), organized in parallel with the analyses of variance discussed above. No column is given for "Sign" since the sign is positive, after adjustment for covariates, in every analysis.

From experience with the Phase I analyses, the various analyses of variance were planned as the main analyses. The covariance analyses were done to check the Phase I covariance analyses, when use of the covariates was not helpful and two possible covariates, band passage time or duration and control area precipitation, removed any possible existing effects of seeding. In each of our tables, analyses of variance and covariance are highly correlated since the same convective bands are involved for all ground-seeded data and for all aerial-seeded data. The various target areas were used to compare near and far-away effects of seeding; we see no differences from one target area to another. The analyses of variance for ground-seeded data give no indication of a seeding effect, even with removal of the one extreme-precipitation, not-seeded storm. There is little indication of a seeding effect when all aerial-seeded bands are considered, but removal of the four storms, for which some bands were seeded and some not seeded, yielded significances at the one-sided 0.05 level in Table IX(b), Part 2, significances comparable to those observed with the ground-seeded, Phase I analyses. While the four storms were removed because of defect in following the experimental plan to seed or not

seed all bands in a storm, it happened that all non-seeded bands removed had higher mean precipitations than the seeded bands removed. It is apparent that a few bands or storms can have a major effect on the outcome of the experiment. We believe that better control in the determination of seedable convective bands is needed.

It was noted in Section 4 that there was some confounding of treatment and storm effects because of disproportionate numbers of bands in storms and variations in the numbers of operative raingages. The extent of the problem depends on the relative sizes of k_1 and k_2 in (4.4). We have calculated $k_1 = 217.03$ and $k_2 = 244.33$ for Target Area (i), ground-seeded bands, in Table IV(a). In addition, considering the expected mean squares in (4.3), we estimate σ_s^2 and σ^2 respectively as 15.44 and 0.121. The experimental error mean square underestimates the error component in the treatment mean square by 3.25. The test of significance is biased in the direction of finding an apparent treatment effect. Even so, significances were not found except in Table IV(b), Part 2. Let us similarly examine the Target Area (i) analysis of variance in Table IV(b), Part 2. Now $k_1 = 140.05$ and $k_2 = 165.228$, but in this analysis of variance the experimental error is smaller than the sampling error as estimated by their mean squares and we must estimate σ^2 as zero. The analyses of variance in Table IV(b), Part 2, seem appropriate if deletion of the mixed storms is appropriate.

A difference between the analyses of variance for ground-seeded analyses and aerial-seeded analyses is now apparent. For ground-seeded data, the experimental error is two to three times as large as the sampling error and this was expected intuitively in the thought that variability among storms treated alike should be greater than variability among bands treated alike within the same storms. But

this is not the case with the aerial-seeded data, as mean squares for experimental error and sampling error are very nearly equal in all of the analyses of variance. We do not have an explanation for this apparent phenomenon.

One may note that the magnitudes of mean squares, particularly for sampling error, vary substantially from one target area to another in the same table. This results because the Δ's in the transformations as exhibited in Tables III(a) and III(b) vary over the target areas. The mean squares vary inversely as Δ^2 as an approximation and this largely accounts for the variation in sampling error mean squares observed.

We turn to discussion of the analysis of covariance in Tables A-4(a), A-4(a) Continued, A-4(b), Part 1, and A-4(b), Part 2. No significances for seeding result for the ground-seeded data in Table A-4(a) for any of the five target areas or any of the four models. The covariates do substantially reduce sampling error mean squares and experimental error mean squares and increase the seeding or treatment mean squares, F-ratios becoming considerably larger than in corresponding analyses of variance. Control area precipitation is the most effective covariate, followed by duration or band passage time, while the basic six cloud-physics covariates are only moderately effective. The effectiveness of covariate sets is assessed by examination of F-ratios formed by the ratios of covariates mean squares to corresponding sampling error mean squares. The F-ratios for seeding are the ratios of seeding mean squares to experimental error mean squares.

Comments on the analyses of covariance in Table A-4(a) Continued for ground-seeded data with the extreme storm omitted are similar to those for Table A-4(a). The covariates have been a little less effective, perhaps because they provided a major adjustment when the extreme, not-seeded storm was included. Borderline,

one-sided significances for seeding are achieved for target areas (i), (iii), and (iv) for model (3) with the six basic covariates and duration. The possible effect may well be in target area (iii), the downwind area included in both (i) and (iv). The apparent significances should be discounted in analogy with the problems with k_1 and k_2 in the corresponding analyses of variance.

Only covariate models (2) and (3) could be considered for the aerial-seeded data, since X_c was not available because no control area could be used. From Tables A-4(b), Part 1, and A-4(b), Part 2, it is seen that use of the covariates has reduced sampling error and experimental error mean squares but treatment or seeding mean squares are also reduced so that the general effect has been to reduce F-ratios for seeding somewhat. The covariate, duration, plays no effective role for the aerial-seeded data. The covariate analyses here are ineffective with results rather similar to those of the Phase I analyses for ground-seeded data.

No clear explanation of the differences in the effectiveness of use of covariates for ground-seeded and aerial-seeded data in the Phase II experimentation is apparent. The cloud-physics covariates were measured deeper in the target area relative to seeding location for the aerial-seeded data. Examination of the correlations in Tables A-3(a) and A-3(b) shows that the basic cloud-physics covariates have somewhat higher correlations with transformed precipitation means for the aerial-seeded data while the similar correlation for duration is smaller for the aerial-seeded data. For the aerial-seeded data correlations between the covariates and the seeding variable Z are somewhat higher. These results are consistent with the results of the covariance analyses but do not provide the desired explanation.

Tables A-5(a), A-5(a) Continued, A-5(b), Part 1, and A-5(b), Part 2, show regression coefficients for the eight covariates of Model (5) for ground-seeded data and the seven covariates of Model (3) for aerial-seeded data, together with the regression coefficient for seeding, the latter always being positive. Some comparisons of these regression coefficients may be made with similar tables of Bradley, Srivastava and Lanzdorf (1979a). These tables essentially confirm comments above in regard to the covariance analyses. X_6, 500 mb temperature, seems to play a bigger role in ground-seeded experimentation than in aerial-seeded experimentation - this temperature was regarded as important by the experimenters. X_7, stability class, is the second most important of the six basic covariates, and seems to have equally important roles in both ground-seeded and aerial-seeded experimentation. Control area precipitation is important, as observed above, in ground-seeded analyses. The role of X_{12}, duration, is reduced when X_c is included in the model and X_{12} is important in the aerial-seeded analyses.

6. CONCLUDING REMARKS

Phase II of the Santa Barbara Convective Band Seeding Test Program was a relatively small experiment in weather modification when the inherent large variability of band precipitation and the two-part design are considered. The ground-seeded part of the experiment was reduced to twelve experimental units, one of them at least suspect. The aerial-seeded part of the experiment consisted of 30 experimental units when four mixed storms are counted double and 22 experimental units if they are omitted. No seeding effects were significant in the analyses of the ground-seeded data except in one covariance analysis for target areas (i), (iii) and (iv) when a high precipitation, not-seeded storm was omitted. No seeding effects were significant in the analyses of the aerial-seeded data until the four mixed storms were omitted (See Table IV(b)) and covariance analyses removed the apparent effect of seeding even in that situation, apparently because the covariates were correlated with treatment as in the analyses of the Phase I data. We can only conclude that both phases of the Santa Barbara study are suggestive of an effect of cloud seeding, but that the effect has not been sufficiently well established for general scientific acceptance. It is the personal opinion of the principal investigator that the experimental results have sufficient promise to justify further similar research if improved experimental design as discussed below could be effected.

The Phase II experiment seems to have yielded data that is particularly sensitive to the inclusion or exclusion of certain storms. We have seen this as the one extreme storm is omitted from analyses of the ground-seeded data and the four mixed storms are omitted from analyses of the aerial-seeded data. We have seen that the use of covariates is apparently helpful with the ground-seeded analyses, contrary

to indications from the Phase I, ground-seeded analyses, but not helpful with the aerial-seeded analyses. We can provide no explanation of this situation except to suspect that extreme values of the covariates, measured subject to substantial errors also, may distort their effects. We see no particular justification for omitting the extreme storm from the ground-seeded data and only partial justification for omitting the four mixed storms from the aerial-seeded data.

Brillinger, Jones and Tukey (1978, pp. G-8, G-9) discuss exceptional events and comment on both orographic rainfall and hail storms. We quote from the report:

> "The only way we can see to tackle instances of such problems of extreme difficulty is to eliminate the exceptional character of such events. The only likely way in which this might be done would be to learn enough about such storms as phenomena to be able, from concomitant measurements, to be able to predict their untreated behaviour at least moderately well."

It has been our view throughout that the major hope in the improved design and analysis of future weather modification lies in the identification and measurement of improved concomitant variables or covariates. The cloud-physics covariates used in the Santa Barbara experiments were reasonably effective in reducing experimental errors, but they were suspect since they were measured in the area of expected response to cloud seeding. Two other covariates, simple in conception, control area precipitation and duration or band passage time, may be even more effective if they can be measured at pertinent locations unaffected by cloud seeding. It may be that extensive meteorological research is needed before really good covariates are identified.

In the Phase I experimentation, with convective bands as experimental units, criteria were established for the selection of "seedable" convective bands, acceptable experimental units, although difficulties in application of the criteria were encountered. In the Phase II experimentation, with storms as experimental units, the criteria were apparently applied to the first convective band of the storm, but it is not clear if they were applied to the subsequent bands in the same storm. The selection of appropriate experimental units appears to be of crucial importance and it may be that failure of proper selectivity led to problems encountered in analyses of the Phase II data. Proper selection may depend on proper concomitant variables. If it is not possible to select experimental units from appropriate criteria prior to inclusion in an experiment, proper criteria, applied post facto, could be developed to determine whether or not the unit is included or omitted from the experiment, the decision to be made by a meteorologist unaware of whether or not the unit was seeded. Recall that the meteorologist determining raingage precipitations was deliberately uninformed as to whether or not the convective band had been seeded.

We are inclined to think that the changes to the storm as the experimental unit instead of the convective band in the Phase II experiment was a mistake. The change complicates analyses and reduces the available number of experimental units per season substantially. Only serious concern for a persistence effect of seeding from a seeded band to a subsequent not-seeded band seems to justify the design change.

We continue to have some concerns about the determination of precipitation attributable to a particular convective band at a raingage and suspect that this may be an additional source of experimental variation. We have not been involved in such determinations but the procedure has been shown to us. This seems not to have given the experimenters concern, but further study is indicated.

Given a substantial body of data, further statistical analyses are always possible. Thought has been given to analyses other than those that we have reported. But it is our judgment that analyses completed have exhibited the essential results or lack of them. Concerns about multiplicity of analyses, often expressed relative to weather modification experiments, are real. Some combination of analyses for the Phase I and Phase II data sets might have been attempted. But the design changes made for the Phase II experimentation made this very difficult and any attempt seemed likely to be unproductive.

In summary, the Santa Barbara studies seem to have been done carefully within the state of the art and with full scientific integrity. Experimentation with winter storms on the West Coast may well hold more hope for the clear demonstration of the effects of cloud seeding than other types of effort in weather modification. The success of future experiments seems likely to depend on the use of better covariates, avoidance of possible seeding effects on the covariates, choice of good control areas, better selectivity of acceptable experimental units, the use of convective bands as experimental units, if possible persistence effects can be discounted, and the use of experimental designs that allow for storm effects as a source of variation.

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APPENDIX TABLES

TABLE NOTES

Appendix Tables are in two parts, Parts (a) for the ground-seeded data and Parts (b) for the aerial-seeded data of Phase II of the Santa Barbara experiment.

A-1. Notes on Tables A-1. Tables A-1(a) and A-1(b) provide summaries of raingage precipitation data for eight ground areas described in the body of this report. For each convective band, the average precipitation in inches from the operative raingages in the designated area appears in columns headed MEAN and the corresponding variance among observations at these raingages is provided in columns headed VAR. The number of operative raingages is given in columns headed NUM. Convective bands are listed by storm number (columns labeled ST) and band number within storm (columns headed BD) given in time sequence. Whether or not a band was seeded is indicated in the third column headed TR.

In Table A-1(b), it will be noted that some storms have been divided because the treatment decision was not applied to all bands within the storm as intended in the experimental plan. Storms 91 and 92 at the top of Table A-1(b) are examples. In our analyses, such storms were treated as two storms. The first two bands of storm 91 were treated as bands from a two-band, seeded storm whereas the third band of storm 91 was treated as a band from a one-band, not seeded storm.

In Table A-1(a), storm 4, band 1 has extremely large means and the means for storm 8, band 2 are also quite large. These bands are discussed in the body of the report.

A-2. Notes on Tables A-2. Gleeson (1977) identified and tabulated concomitant variables for Phase I of the Santa Barbara experiment. Similar tabulations are provided in Tables A-2(a) and A-2(b) for the ground-seeded and aerial-seeded convective bands of the Phase II data.

There are only minor changes in these new tables. Convective bands have both a Band Number and a Storm-Band Number, the latter designation matching that in Tables A-1. Dates of bands and beginning and ending times of band passage at the seeding site have been omitted as has the station of radiosonde observation. Other concomitant variables have been recorded as before. Parentheses in the tables indicate less reliable entries because some data were missing.

The concomitant variables are listed with brief explanations. See Gleeson (1977) or Bradley, Srivastava and Lanzdorf (1979) for additional details. The concomitant variables are:

Duration: Time in hours of band passage at the seeding site.

Treatment: Seeded band-S; not seeded band - NS.

Radiosonde: Number of the radiosonde used to represent atmospheric conditions associated with the band.

Time (PST): Time of radiosonde release.

Mixing Ratio: A measure of water-vapor content in the air in grams of water vapor per 1000 grams of dry air.

700-MB Speed: Wind speed in knots of 700-mb (10,000 ft.) horizontal wind.

Direction, 700-MB Wind: Wind direction, degrees east of north.

Mean Speed, Wind: Mean speed in knots of horizontal winds from 1000 ft. to 14,000 ft. elevation.

Direction, Mean Wind: Average wind direction of average vector wind, degrees east of north.

500-MB Temperature: Cloud-top temperature, degree Celsius, approximately 19,000 ft.

Stability Class: UL-unstable with low convective stability base, UH-unstable with high convective stability base, ST-stable, scored respectively, 1,2,3.

Showalter Index: A measure of atmospheric stability, large positive (negative) values indicate stability (instability).

Stability Wind: Speed in knots of a theoretical wind.

Direction, Stability Wind: Direction of the stability wind, degrees east of north.

Instability Transport: A time rate of horizontal movement of less stable air measured in knots squared.

A-3. Notes on Tables A-3. Tables A-3(a) and A-3(b) show simple correlation coefficients among the concomitant variables listed in (3.1) and X_c, band precipitation mean for response area (v), the control area for ground-seeded data, the mean based on the Bureau of Reclamation raingage network. Detail on the concomitant variables is given above in Section A-3. The mean of transformed precipitation responses for Area (i) for a band is designated z in these tables and Z is the indicator variable for seeding, Z = 1 if a band is seeded and Z = 0 otherwise. Pairwise correlation coefficients are given for the variates, $X_1, \ldots, X_{12}$, X_c, z and Z. Some comments on these tables are given in Section 3 of the report.

A-4. Notes on Tables A-4. Tables A-4(a), A-4(a) Continued, A-4(b), Part 1, and A-4(b), Part 2, provide analyses of covariance for the appropriate models of (3.2). The method of covariance analysis is discussed in Section 4. Only mean squares and pertinent F-ratios are shown together with corresponding degrees of freedom. Complete analysis of covariance tables may be reconstructed from the information given. In particular sums of squares may be obtained and it can be checked that the total sums of squares are equal for analyses within tables and check with those of the corresponding analysis of variance tables in Section 5. It can be checked that the effect of adding covariates is always to reduce the sampling error sum of squares, although not always to reduce the sampling error mean square because of loss of degrees of freedom. Seeding and experimental error sums of squares always add to the Subtotal sum of squares.

A-5. Notes on Tables A-5. Tables A-5(a), A-5(a) Continued, A-5(b), Part 1, and A-5(b), Part 2, give the regression coefficients for the covariates of Model (5) for ground-seeded analyses and for the covariates of Model (3) for aerial-seeded analyses, together with the regression coefficient for seeding or treatment. Intercomparisons may be made among these tables and Tables A-5(a) and A-5(a) Continued may be compared with the corresponding Table A-3 for ground-seeded data given by Bradley, Srivastava and Lanzdorf (1979a).

TABLE A-1(a): PHASE II PRECIPITATION DATA, GROUND-SEEDED BANDS

			AREA ONE			AREA TWO			AREA THREE			AREA FOUR		
ST	BD	TR	MEAN	VAR	NUM	MEAN	VAR	NUM	MEAN	VAR	NUM	MEAN	VAR	NUM
4	1	NS	1.3243	.489637	84	1.8322	.991418	18	1.2532	.259105	59	1.3886	.480342	77
7	1	NS	.0146	.000711	69	.0324	.000482	17	.0098	.000756	44	.0161	.000774	61
7	2	NS	.0388	.003940	69	.1082	.006453	17	.0155	.001156	44	.0413	.004308	61
8	1	S	.0899	.009125	88	.1852	.009336	21	.0616	.005575	63	.0925	.009315	84
8	2	S	.9983	.176499	88	1.1848	.205787	21	.9652	.146516	65	1.0201	.168177	84
8	3	S	.2633	.024100	88	.3090	.023259	21	.2576	.024038	63	.2705	.024063	84
9	1	NS	.6770	.486244	88	1.3786	.776364	21	.4498	.191134	63	.6820	.493525	84
9	2	NS	.3643	.022884	89	.4590	.021469	21	.3447	.018235	64	.3729	.021249	85
10	1	S	.4249	.054349	90	.3770	.036327	20	.4875	.044045	61	.4602	.043962	81
10	2	S	.0485	.003213	92	.1142	.003370	19	.0287	.001376	64	.0483	.003102	83
11	1	NS	.0184	.000762	97	.0311	.000899	19	.0165	.000734	68	.0197	.000796	87
11	2	NS	.1453	.016744	97	.1358	.007792	19	.1660	.018979	68	.1594	.016575	87
14	1	S	.1596	.009574	101	.2274	.011456	23	.1454	.004966	69	.1659	.007756	92
14	2	S	.2478	.022433	101	.1835	.008615	23	.2864	.018226	69	.2607	.017709	92
17	1	NS	.2210	.023322	93	.2350	.025268	20	.2264	.019226	67	.2284	.020351	87
17	2	NS	.0815	.008848	93	.0605	.009731	20	.0951	.008607	67	.0871	.008970	87
17	3	NS	.2010	.055280	93	.2310	.021999	20	.2087	.067188	67	.2138	.056512	87
21	1	S	.1618	.036337	91	.3577	.046618	22	.0956	.012763	62	.1643	.034613	84
21	2	S	.0971	.016099	91	.1950	.013836	22	.0569	.003740	62	.0931	.009978	84
22	1	S	.1105	.018923	94	.2529	.028162	21	.0718	.009314	66	.1155	.019660	87
22	2	S	.1956	.052272	94	.3657	.065336	21	.1552	.040828	66	.2060	.054266	87
22	3	S	.4406	.100765	94	.4519	.084716	21	.4756	.102016	66	.4699	.096910	87
22	4	S	.1660	.024194	94	.2200	.036920	21	.1636	.020150	66	.1772	.024404	87
22	5	S	.1640	.022709	93	.1833	.042263	21	.1692	.016132	65	.1727	.022128	86
22	6	S	.1058	.006757	93	.1390	.008789	21	.1052	.005582	65	.1135	.006484	86
30	1	S	.1985	.014788	89	.1990	.014139	21	.2148	.013370	62	.2108	.013442	83
30	2	S	.2145	.017593	89	.1786	.011183	21	.2444	.016582	62	.2277	.015891	83
30	3	S	.2779	.044556	89	.4805	.070195	21	.2319	.018734	62	.2948	.042674	83
30	4	S	.2576	.026659	89	.1819	.009886	21	.3042	.025598	62	.2733	.024315	83
34	1	S	.1949	.033272	90	.3648	.057006	21	.1445	.016917	60	.2016	.036161	81

TABLE A-1(a)(Continued): PHASE II PRECIPITATION DATA, GROUND-SEEDED BANDS

			AREA FIVE			AREA SIX			AREA SEVEN			AREA EIGHT		
ST	BD	TR	MEAN	VAR	NUM	MEAN	VAR	NUM	MEAN	VAR	NUM	MEAN	VAR	NUM
4	1	NS	1.4813	.542451	31	1.3666	.504137	115	1.4081	.503227	36	1.3969	.727976	49
7	1	NS	.1388	.005536	25	.0477	.004990	94	.1674	.017100	31	.0252	.000908	42
7	2	NS	.0692	.001575	26	.0472	.003455	95	.0712	.003353	32	.0652	.004972	42
8	1	S	.0927	.008180	26	.0905	.008837	114	.1130	.009847	33	.1349	.009656	47
8	2	S	.9252	.263311	27	.9811	.195719	115	.9003	.238034	34	1.0587	.243602	47
8	3	S	.3763	.017109	27	.2898	.024609	115	.3885	.025964	34	.3057	.026734	47
9	1	NS	.8131	.205294	26	.7081	.423071	114	.8106	.200355	32	.9538	.693994	47
9	2	NS	.3411	.010626	27	.3589	.020010	116	.2936	.020161	33	.4077	.032401	47
10	1	S	.3990	.024220	20	.4202	.048699	110	.4111	.055603	27	.2945	.043489	51
10	2	S	.0660	.001499	20	.0516	.002936	112	.0537	.001593	27	.0598	.004146	51
11	1	NS	.0226	.001038	23	.0192	.000809	120	.0420	.005554	30	.0174	.000646	54
11	2	NS	.2743	.019635	23	.1700	.019741	120	.2517	.022221	30	.0891	.006182	54
14	1	S	.2036	.019920	28	.1591	.012013	129	.2097	.048397	35	.1810	.014153	58
14	2	S	.1507	.005799	28	.2267	.020364	129	.1489	.006675	35	.2057	.023463	58
17	1	NS	.1742	.042806	33	.2087	.028549	126	.1558	.339463	38	.2347	.036368	53
17	2	NS	.2297	.017159	33	.1203	.015184	126	.2153	.017026	38	.0513	.006466	53
17	3	NS	.1630	.011341	33	.1910	.043870	126	.1782	.020945	38	.2225	.075746	53
21	1	S	.3875	.116691	32	.2205	.066346	123	.3765	.106802	37	.2415	.041583	55
21	2	S	.1750	.027090	32	.1174	.019936	123	.1708	.025119	37	.1375	.021031	55
22	1	S	.2618	.062628	33	.1498	.034309	127	.2546	.057089	39	.1611	.024569	54
22	2	S	.1076	.019531	33	.1728	.045045	127	.1010	.017746	39	.2770	.068844	54
22	3	S	.1706	.011062	33	.3705	.091319	127	.1762	.013272	39	.3587	.088936	54
22	4	S	.1509	.011796	33	.1620	.020897	127	.1556	.012841	39	.1493	.023252	54
22	5	S	.0609	.004115	33	.1370	.019837	126	.0713	.007922	39	.1681	.034159	54
22	6	S	.2058	.032488	33	.1320	.015237	126	.2403	.040997	39	.1007	.006943	54
30	1	S	.1893	.012984	27	.1964	.014267	116	.1658	.013319	33	.1938	.018063	47
30	2	S	.1430	.008975	27	.1978	.016413	116	.1448	.008101	33	.1964	.020093	47
30	3	S	.1519	.014300	27	.2485	.040188	116	.1756	.034309	32	.3296	.066678	47
30	4	S	.1715	.009975	27	.2376	.023992	116	.1830	.014665	33	.2351	.030787	47
34	1	S	.6021	.053240	28	.2915	.067870	118	.6353	.080583	34	.2261	.040532	51

TABLE A-1(b): PHASE II PRECIPITATION DATA, AERIAL-SEEDED BANDS

			AREA ONE			AREA TWO			AREA THREE			AREA FOUR		
ST	BD	TR	MEAN	VAR	NUM	MEAN	VAR	NUM	MEAN	VAR	NUM	MEAN	VAR	NUM
91	1	S	.0374	.001286	94	.0467	.001371	24	.0382	.001248	62	.0406	.001281	86
91	2	S	.0560	.002457	94	.0687	.002116	24	.0534	.002354	62	.0577	.002310	86
91	1	NS	.1027	.007134	94	.0787	.002872	24	.1211	.008394	62	.1093	.007167	86
92	1	NS	.0033	.000067	90	.0019	.000036	21	.0043	.000085	61	.0037	.000073	82
92	1	S	.0032	.000060	90	.0010	.000009	21	.0044	.000082	61	.0035	.000065	82
93	1	NS	.0249	.001041	76	.0350	.001227	14	.0239	.001053	56	.0261	.001091	70
93	2	NS	.0163	.000651	75	.0364	.001486	14	.0120	.000390	55	.0170	.000692	69
1	1	NS	.0880	.006249	88	.1375	.011241	20	.0800	.003905	60	.0944	.006248	80
2	1	NS	.0527	.004076	84	.0660	.000994	20	.0552	.005371	56	.0580	.004213	76
3	1	S	.2766	.039789	98	.3939	.040252	23	.2636	.032064	66	.2973	.037036	89
3	1	NS	.5310	.080353	97	.4895	.059719	22	.5926	.070072	66	.5668	.068780	88
5	1	NS	.0010	.000028	88	.0037	.000102	19	.0003	.000007	60	.0011	.000031	79
6	1	S	.0111	.000401	88	.0052	.000146	21	.0145	.000513	59	.0120	.000429	79
6	2	S	.1260	.006137	88	.1724	.005459	21	.1193	.005635	58	.1334	.006274	79
12	1	S	.0179	.000579	96	.0341	.001054	22	.0122	.000373	65	.0177	.000627	87
12	2	S	.1298	.008567	97	.1765	.004524	23	.1211	.008697	65	.1356	.008269	88
12	1	NS	.2253	.023198	97	.1926	.006447	23	.2472	.027067	65	.2330	.022124	88
13	1	NS	.0552	.009013	98	.1759	.010832	22	.0122	.000918	67	.0527	.009327	89
14	1	S	.7853	.223155	101	.7813	.186894	23	.8630	.205737	69	.8426	.200186	92
14	2	S	.3617	.028674	101	.4461	.024352	23	.3533	.026172	69	.3765	.027076	92
15	1	NS	.8807	.289814	100	1.1158	.417930	24	.8710	.196899	68	.9349	.262282	92
16	1	S	.3090	.051794	94	.1645	.012068	20	.3785	.048959	68	.3299	.045477	88
18	1	S	.5929	.190152	94	.7755	.213647	20	.5767	.180635	66	.6229	.193028	86
19	1	NS	.4666	.055716	89	.4153	.040371	19	.5216	.047958	62	.4967	.047707	81
20	1	NS	.0023	.000046	94	.0057	.000096	21	.0015	.000032	65	.0026	.000050	86
20	2	NS	.0383	.002913	94	.0495	.002175	21	.0348	.003278	65	.0384	.003021	86
23	1	NS	.2173	.024231	90	.2871	.038035	17	.2102	.021205	65	.2261	.025251	82
24	1	NS	.4521	.033877	91	.4911	.041276	19	.4653	.027546	64	.4712	.030343	83
24	2	NS	.0497	.004674	91	.0174	.003287	19	.0622	.004836	64	.0519	.024796	83
25	1	S	.8667	.182720	87	1.2025	.313325	20	.7938	.095551	61	.8947	.177530	81
25	2	S	.1199	.004884	85	.1360	.005236	20	.1146	.003894	59	.1200	.004259	79
26	1	NS	.3428	.081296	86	.5029	.112847	17	.3383	.064580	60	.3747	.078615	77
26	2	NS	.4242	.078281	86	.6400	.121687	17	.3930	.057754	60	.4475	.081087	77
27	1	S	.0362	.011554	93	.1495	.013447	20	.0767	.010777	63	.0942	.012247	83
27	2	S	.7120	.324558	93	1.3190	.349915	20	.5759	.208234	63	.7549	.340759	83
28	1	S	.1656	.010685	94	.1309	.003254	23	.1858	.011733	64	.1713	.010020	87
29	1	NS	.0140	.000769	88	.0114	.000022	22	.0159	.000864	62	.0140	.000766	84
29	2	NS	.5252	.062722	88	.4286	.052489	22	.5797	.055633	62	.5401	.056030	84
29	3	NS	.7452	.114849	84	.9800	.141821	20	.6868	.079737	60	.7601	.139978	80
31	1	NS	.0297	.000416	94	.0243	.000917	23	.0030	.000121	63	.0087	.002416	86
32	1	NS	.0002	.000005	88	0.0000	0.000000	20	.0003	.000007	59	.0003	.000005	79
32	2	NS	.0017	.000046	88	.0010	.000009	20	.0010	.000020	59	.0010	.000017	79
32	3	NS	.1834	.023581	88	.2190	.026862	20	.1893	.021297	59	.1961	.022500	79
32	4	NS	.3953	.054399	87	.4311	.040454	19	.4185	.053013	59	.4215	.049118	78
33	1	S	.2862	.046720	88	.5214	.052103	21	.2322	.019340	58	.3091	.044024	79

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TABLE A-1(b)(Continued): PHASE II PRECIPITATION DATA, AERIAL-SEEDED BANDS

ST	BD	TR	AREA FIVE MEAN	AREA FIVE VAR	AREA FIVE NUM	AREA SIX MEAN	AREA SIX VAR	AREA SIX NUM	AREA SEVEN MEAN	AREA SEVEN VAR	AREA SEVEN NUM	AREA LIGHT MEAN	AREA LIGHT VAR	AREA LIGHT NUM
91	1	S	.0456	.001326	27	.0393	.001295	121	.0641	.007154	32	.0387	.001165	54
91	2	S	.0752	.003526	27	.0602	.002732	121	.0697	.003216	32	.0554	.001644	54
91	1	NS	.0715	.002767	27	.0957	.006298	121	.0706	.002613	32	.0772	.003583	54
92	1	NS	.0054	.000078	28	.0038	.000070	118	.0070	.000166	33	.0014	.000024	51
92	1	S	.0093	.000162	28	.0047:	.000090	118	.0079	.000148	33	.0014	.000016	51
93	1	NS	.0812	.000855	24	.0384	.001573	100	.0886	.001753	28	.0280	.001006	41
93	2	NS	.0432	.000923	25	.0230	.000823	100	.0503	.001825	29	.0166	.000788	41
1	1	NS	.0821	.001396	29	.0665	.005030	117	.0900	.004242	34	.1059	.000125	51
2	1	NS	.1752	.003569	29	.0842	.006825	113	.1772	.006969	36	.2398	.001315	49
3	1	S	.2693	.073664	29	.2750	.047011	127	.2928	.065586	36	.3087	.054615	55
3	1	NS	.3011	.066313	28	.4795	.085914	125	.3400	.073312	35	.4378	.109921	55
5	1	NS	.0071	.000155	28	.0025	.000064	116	.0338	.004236	34	.0017	.000045	53
6	1	S	.0224	.000476	29	.0139	.000440	117	.0253	.000591	36	.0131	.000477	52
6	2	S	.0834	.003002	29	.1155	.005068	117	.0753	.002843	36	.1387	.007624	52
12	1	S	.1437	.004493	27	.0455	.004141	123	.1412	.004548	33	.0279	.000730	56
12	2	S	.1141	.00814:	27	.1264	.009451	124	.1312	.009455	33	.1633	.008726	57
12	1	NS	.2385	.012159	27	.2281	.020706	124	.2697	.017472	33	.2146	.028429	57
13	1	NS	.2952	.043264	27	.1070	.024542	125	.2936	.034736	33	.1087	.010196	56
14	1	S	.7666	.143187	29	.7856	.204068	130	.7508	.135197	36	.7359	.202477	58
14	2	S	.2797	.020611	29	.3434	.027877	130	.3200	.032291	36	.3602	.031567	58
15	1	NS	.7359	.262595	27	.8499	.295434	127	.9544	.332547	34	.8566	.394307	58
16	1	S	.2129	.023521	31	.2852	.046274	125	.1956	.022300	36	.1711	.023072	53
18	1	S	.6097	.292661	32	.5971	.164507	126	.7011	.176085	38	.6637	.234350	54
19	1	NS	.4144	.028470	32	.4528	.048749	121	.4300	.036465	38	.4032	.066528	50
20	1	NS	.0028	.000047	32	.0025	.000046	126	.0092	.000307	39	.0044	.000082	54
20	2	NS	.0881	.005913	32	.0510	.004138	126	.0977	.006650	39	.0361	.002334	54
23	1	NS	.2200	.006767	31	.2180	.019664	121	.2539	.014144	36	.2466	.029370	50
24	1	NS	.3387	.005626	30	.4240	.029186	121	.3306	.009670	35	.4375	.036911	51
24	2	NS	.0453	.001729	30	.0486	.003927	121	.0474	.001887	34	.0314	.002736	51
25	1	S	.9863	.063832	27	.8950	.156358	114	1.0187	.094560	32	.9548	.287374	48
25	2	S	.3348	.013172	27	.1717	.015310	112	.3606	.019142	32	.1272	.007325	46
26	1	NS	.2320	.018794	30	.3144	.067159	116	.2794	.047700	35	.3344	.087791	43
26	2	NS	.4976	.029746	29	.4427	.066699	115	.5179	.039074	34	.4552	.132825	46
27	1	S	.1626	.019466	31	.1103	.015145	124	.1781	.010965	36	.0950	.015296	52
27	2	S	.9343	.122501	30	.7663	.283055	123	.9437	.122542	35	.8537	.405518	52
28	1	S	.3653	.049681	30	.2140	.027166	124	.4040	.074295	35	.1406	.009500	52
29	1	NS	.0326	.000912	27	.0183	.000858	115	.0347	.001277	32	.0070	.000330	47
29	2	NS	.4763	.037055	27	.5137	.056752	115	.5041	.036251	32	.4468	.059378	47
29	3	NS	.8319	.054262	27	.7663	.100878	111	.8619	.062448	32	.7593	.140658	44
31	1	NS	.0927	.002636	26	.0277	.002358	120	.1028	.005260	32	.0167	.000719	51
32	1	NS	.0023	.000067	30	.0008	.000021	118	.0154	.001708	35	.0001	.000006	51
32	2	NS	.0207	.000941	30	.0065	.000312	118	.0431	.005287	35	.0045	.000133	51
32	3	NS	.1850	.012902	30	.1838	.020733	118	.1934	.013688	35	.2353	.029909	51
32	4	NS	.5623	.074405	30	.4381	.064298	117	.5429	.067727	35	.3728	.051502	50
33	1	S	.3856	.012310	27	.3096	.040250	115	.3558	.017463	33	.3408	.064246	51

TABLE A-2(a): PHASE II CONCOMITANT OBSERVATIONS, GROUND-SEEDED BANDS

BAND NUMBER AND STORM-BAND NUMBER

VARIABLE	108 4-1	109 7-1	110 7-2	111 8-1	112 8-2	113 8-3	114 9-1	115 9-2	116 10-1	117 10-2
DURATION	4.33	2.75	1.17	.92	3.00	.83	5.53	2.02	4.00	.83
TREATMENT	NS	NS	NS	S	S	S	NS	NS	S	S
RADIOSONDE	243	248	249	251	252	253	257	259	261	262
TIME(PST)	315	815	934	2400	321	345	2143	1203	315	822
MIXING RATIO	3.8	4.5	4.7	4.8	4.5	5.4	4.8	4.5	6.2	4.7
700-MB SPEED	60	38	32	48	43	43	44	27	43	54
DIRECTION, 700-MB WIND	207	225	241	228	225	225	209	260	270	268
MEAN SPEED, WIND	34	25	21	29	33	33	27	17	36	38
DIRECTION, MEAN WIND	218	224	237	190	218	220	184	249	270	277
500-MB TEMP.	-25.4	-19.1	-19.5	-20.2	-21.7	-21.7	-20.1	-22.8	-17.0	-18.3
STABILITY CLASS	UL	UL	UL	UL	UL	UH	UL	UL	UL	UL
SHOWALTER INDEX	1	6	5	3	4	1	6	5	3	10
STABILITY WIND	65	47	39	63	61	63	68	32	71	69
DIRECTION, STAB. WIND	217	224	235	185	223	221	175	241	273	300
INSTABILITY TRANSPORT	-528	106	22	-634	-50	268	-97	79	82	-1025

TABLE A-2(a)(Continued): PHASE II CONCOMITANT OBSERVATIONS, GROUND-SEEDED BANDS

VARIABLE	BAND NUMBER AND STORM-BAND NUMBER									
	118	119	120	121	122	123	124	125	126	127
	11-1	11-2	14-1	14-2	17-1	17-2	17-3	21-1	21-2	22-1
DURATION	2.10	2.83	1.87	1.57	2.00	2.13	1.08	4.25	1.50	2.57
TREATMENT	NS	NS	S	S	NS	NS	NS	S	S	S
RADIOSONDE	263	265	270	271	279	280	281	290	289	292
TIME(PST)	1113	(1530)	400	1050	2400	927	1515	530	400	928
MIXING RATIO	2.9	3.8	5.4	6.0	4.5	4.4	3.9	4.6	4.8	4.6
700-MB SPEED	44	30	33	33	27	31	30	43	40	36
DIRECTION, 700-MB WIND	280	275	270	270	225	226	225	237	230	210
MEAN SPEED, WIND	23	22	26	22	25	24	26	31	34	26
DIRECTION, MEAN WIND	276	259	232	247	189	213	213	210	203	192
500-MB TEMP.	-17.3	-19.9	-15.2	-15.2	-23.4	-23.8	-23.4	-20.0	-21.0	-18.5
STABILITY CLASS	UL	UL	UL	UL	UL	UL	UL	UH	UL	UL
SHOWALTER INDEX	13	8	6	5	3	0	3	7	3	3
STABILITY WIND	37	36	49	47	45	46	54	58	62	51
DIRECTION, STAB. WIND	280	259	232	246	179	210	212	193	198	185
INSTABILITY TRANSPORT	-116	-85	-205	23	379	-107	-39	-61	298	213

TABLE A-2(a)(Continued): PHASE II CONCOMITANT OBSERVATIONS, GROUND-SEEDED BANDS

VARIABLE	BAND NUMBER AND STORM-BAND NUMBER 128 22-2	129 22-3	130 22-4	131 22-5	132 22-6	133 30-1	134 30-2	135 30-3	136 30-4	137 34-1
DURATION	1.32	1.28	.47	1.25	1.42	1.03	1.67	1.23	1.50	2.25
TREATMENT	S	S	S	S	S	S	S	S	S	S
RADIOSONDE	293	296	297	298	299	325	326	327	328	340
TIME(PST)	1400	(1613)	(1907)	2130	45	1515	1731	2127	2229	2209
MIXING RATIO	5.1	4.7	5.1	4.6	5.0	4.9	4.2	4.5	5.0	5.9
700-MB SPEED	30	34	28	32	32	34	27	27	28	30
DIRECTION, 700-MB WIND	225	221	225	235	235	235	235	230	226	270
MEAN SPEED, WIND	26	30	28	28	26	26	21	21	20	28
DIRECTION, MEAN WIND	206	213	224	223	230	220	227	222	229	271
500-MB TEMP.	-20.7	-24.2	-20.9	-20.6	-20.6	-20.5	-20.9	-20.2	-20.6	-16.0
STABILITY CLASS	UL	UL	UL	UL	UL	UL	UL	UL	UL	UL
SHOWALTER INDEX	3	-3	1	2	2	5	7	8	8	3
STABILITY WIND	50	70	64	56	52	56	42	43	39	42
DIRECTION, STAB. WIND	207	219	226	227	229	215	226	221	228	264
INSTABILITY TRANSPORT	8	-853	-325	-251	-14	-118	-158	60	-28	-59

TABLE A-2(b): PHASE II CONCOMITANT OBSERVATIONS, AERIAL-SEEDED BANDS

VARIABLE	BAND NUMBER AND STORM-BAND NUMBER									
	138 91-1	139 91-2	140 91-1	141 92-1	142 92-1	143 93-1	144 93-2	145 1-1	146 2-1	147 3-1
DURATION	.92	.50	1.08	.50	.92	.50	.83	.58	.57	1.83
TREATMENT	S	S	NS	NS	S	NS	NS	NS	NS	S
RADIOSONDE	199	197	200	214	216	229	231	232	235	238
TIME(PST)	905	825	940	1445	1515	315	735	1540	1430	1615
MIXING RATIO	5.2	5.5	5.4	3.7	2.0	3.8	2.5	7.2	4.3	3.8
700-MB SPEED	35	38	38	41	33	58	46	26	35	28
DIRECTION, 700-MB WIND	255	268	268	268	265	260	273	243	250	205
MEAN SPEED, WIND	27	29	33	25	22	39	35	14	16	27
DIRECTION, MEAN WIND	250	256	259	270	262	262	277	214	252	190
500-MB TEMP.	-16.7	-17.9	-17.9	-22.8	-24.0	-21.5	-22.4	-16.3	-21.6	-15.9
STABILITY CLASS	UL	UL	UL	UL	UL	UL	UL	UL	UL	UL
SHOWALTER INDEX	5	4	6	9	10	6	10	0	5	8
STABILITY WIND	50	53	58	44	23	73	64	21	29	53
DIRECTION, STAB. WIND	245	252	255	270	260	266	282	197	237	177
INSTABILITY TRANSPORT	364	162	159	70	-73	252	587	111	37	814

TABLE A-2(b)(Continued): PHASE II CONCOMITANT OBSERVATIONS, AERIAL-SEEDED BANDS

VARIABLE	BAND NUMBER AND STORM-BAND NUMBER									
	148 3-1	149 5-1	150 6-1	151 6-2	152 12-1	153 12-2	154 12-1	155 13-1	156 14-1	157 14-2
DURATION	2.00	2.75	1.15	1.30	.58	1.17	1.05	2.10	.47	.73
TREATMENT	NS	NS	S	S	S	S	NS	NS	S	S
RADIOSONDE	239	244	246	247	266	267	268	269	272	273
TIME(PST)	145	1515	1515	2018	1500	1515	2425	(1606)	1318	1515
MIXING RATIO	4.7	2.3	3.9	3.9	5.4	5.0	4.3	3.0	6.0	6.0
700-MB SPEED	50	44	17	25	26	28	40	32	40	46
DIRECTION, 700-MB WIND	210	275	230	228	255	240	230	265	220	230
MEAN SPEED, WIND	46	24	21	16	39	26	39	27	27	33
DIRECTION, MEAN WIND	184	262	208	224	210	229	210	258	208	245
500-MB TEMP.	-17.1	-16.5	-21.0	-24.0	-16.7	-19.7	-19.3	-22.4	-18.0	-15.5
STABILITY CLASS	ST	UL	UL	UL	UL	ST	ST	UL	UL	UL
SHOWALTER INDEX	4	12	1	-1	2	2	.5	6	4	5
STABILITY WIND	84	43	44	31	34	55	71	47	55	65
DIRECTION, STAB. WIND	180	258	208	202	251	223	205	250	211	249
INSTABILITY TRANSPORT	-32	-53	156	242	186	516	654	229	523	28

TABLE A-2(b)(Continued): PHASE II CONCOMITANT OBSERVATIONS, AERIAL-SEEDED BANDS
BAND NUMBER AND STORM-BAND NUMBER

VARIABLE	158 15-1	159 16-1	160 18-1	161 19-1	162 20-1	163 20-2	164 23-1	165 24-1	166 24-2	167 25-1
DURATION	1.38	1.33	.67	1.00	.63	1.18	1.63	.93	1.30	2.18
TREATMENT	NS	S	S	NS	NS	NS	NS	NS	NS	S
RADIOSONDE	274	277	283	286	287	288	304	305	306	309
TIME(PST)	325	900	920	(1700)	(0315)	1206	1520	400	530	2339
MIXING RATIO	4.1	4.2	5.1	3.8	3.2	3.3	4.4	3.8	3.5	4.3
700-MB SPEED	44	38	23	36	21	24	31	28	28	44
DIRECTION, 700-MB WIND	227	181	226	240	245	280	252	255	255	207
MEAN SPEED, WIND	41	37	22	25	17	16	23	23	21	36
DIRECTION, MEAN WIND	207	172	223	221	232	279	244	234	241	203
500-MB TEMP.	-18.5	-20.7	-21.0	-22.6	-23.1	-24.7	-19.7	-28.4	-28.4	-25.4
STABILITY CLASS	UH	UL	UL	UL	UL	UL	UL	UL	UL	UL
SHOWALTER INDEX	3	6	2	6	6	5	7	1	1	4
STABILITY WIND	83	74	41	52	34	22	46	46	40	72
DIRECTION, STAB. WIND	207	171	218	221	238	266	241	230	239	201
INSTABILITY TRANSPORT	-19	583	-132	-448	-314	31	-83	113	-96	-295

TABLE A-2(b)(Continued): PHASE II CONCOMITANT OBSERVATIONS AERIAL-SEEDED BANDS
BAND NUMBER AND STORM-BAND NUMBER

VARIABLE	168 25-2	169 26-1	170 26-2	171 27-1	172 27-2	173 28-1	174 29-1	175 29-2	176 29-3	177 31-1
DURATION	1.50	.95	1.72	1.42	1.83	1.68	1.67	2.02	.88	1.08
TREATMENT	S	NS	NS	S	S	S	NS	NS	NS	NS
RADIOSONDE	310	312	313	316	319	320	322	323	324	329
TIME(PST)	215	1515	1930	2250	400	1600	1600	2258	255	945
MIXING RATIO	4.6	6.1	5.7	4.9	5.0	5.9	3.1	3.8	3.4	4.5
700-MB SPEED	33	44	40	45	38	38	37	46	44	38
DIRECTION, 700-MB WIND	213	225	230	215	217	240	225	192	200	286
MEAN SPEED, WIND	25	36	32	37	33	30	32	40	35	32
DIRECTION, MEAN WIND	234	222	226	199	196	226	196	170	180	295
500-MB TEMP.	-23.9	-16.0	-17.1	-16.8	-18.5	-16.2	-27.2	-27.0	-26.0	-17.5
STABILITY CLASS	UL	UL	UL	UL	UL	UL	UL	UL	ST	ST
SHOWALTER INDEX	6	2	4	10	5	4	6	4	6	7
STABILITY WIND	41	73	61	72	59	51	66	79	67	62
DIRECTION, STAB. WIND	238	216	218	198	186	224	187	164	175	295
INSTABILITY TRANSPORT	266	699	438	-314	131	163	-71	-120	233	701

TABLE A-2(b)(Continued): PHASE II CONCOMITANT OBSERVATIONS, AERIAL-SEEDED BANDS

BAND NUMBER AND STORM-BAND NUMBER

VARIABLE	178 32-1	179 32-2	180 32-3	181 32-4	182 33-1
DURATION	1.22	1.18	1.27	1.00	1.42
TREATMENT	NS	NS	NS	NS	S
RADIOSONDE	330	332	333	334	336
TIME(PST)	1110	1430	(1800)	1600	2330
MIXING RATIO	3.7	4.1	5.6	5.9	5.3
700-MB SPEED	42	36	47	44	26
DIRECTION, 700-MB WIND	241	236	239	230	225
MEAN SPEED, WIND	23	21	28	33	17
DIRECTION, MEAN WIND	218	223	217	213	217
500-MB TEMP.	-16.9	-17.9	-16.3	-15.9	-20.7
STABILITY CLASS	UL	UL	UL	ST	UL
SHOWALTER INDEX	9	2	4	3	3
STABILITY WIND	41	40	56	66	33
DIRECTION, STAB. WIND	217	218	208	208	212
INSTABILITY TRANSPORT	-267	-50	-40	292	-14

TABLE A-3(a): Correlation Coefficients among Means of Transformed Precipitations*, Covariates, and Seeding, Target Area (i), Ground-Seeded Bands

	z	X_c	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}
X_c	.92													
X_1	.10	-.07												
X_2	.23	.47	-.13											
X_3	-.28	-.34	.15	-.07										
X_4	.23	.33	.23	.73	-.11									
X_5	-.15	-.16	.08	.03	.86	-.02								
X_6	-.39	-.39	.45	-.01	.67	-.06	.51							
X_7	-.01	-.01	.11	.22	-.09	.27	-.12	-.06						
X_8	.03	-.07	-.06	-.36	.14	-.56	-.01	.26	.01					
X_9	.33	.36	.28	.62	-.35	.87	-.28	-.18	.19	-.48				
X_{10}	-.14	-.15	.06	.09	.81	.07	.98	.47	-.17	-.09	-.18			
X_{11}	-.07	-.13	.13	-.43	-.06	-.35	-.18	.10	.18	.28	-.44	-.29		
X_{12}	.45	.60	-.08	.41	-.08	.19	-.09	.01	.12	.23	.17	-.16	.14	
Z	.03	-.14	.59	-.02	.03	.35	.00	.32	.19	-.03	.36	.04	-.16	-.34

*z is the Target Area Mean for the transformed data; covariates $X_c, X_1, \ldots, X_{12}$ are defined in (3.1); Z is the seeding indicator variable with Z = 1 if seeding and Z = 0 if no seeding.

TABLE A-3(b): Correlation Coefficients among Means of Transformed Precipitations*, Covariates, and Seeding, Target Area (i), Aerial-Seeded Bands

	z	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}
X_1	.39												
X_2	.22	.05											
X_3	-.66	-.22	-.13										
X_4	.38	.11	.71	-.34									
X_5	-.58	-.21	-.07	.91	-.35								
X_6	.01	.61	.23	.03	.20	-.01							
X_7	.24	.06	.22	-.11	.39	-.14	.13						
X_8	.01	-.10	.20	-.03	.10	.05	.03	.06					
X_9	.50	.11	.73	-.46	.89	-.40	.14	.41	.16				
X_{10}	-.59	-.20	-.05	.90	-.23	.96	.02	-.14	.04	-.36			
X_{11}	.05	.21	.04	-.02	.24	.08	.28	.32	.06	.22	.06		
X_{12}	.18	-.26	.14	-.27	.19	-.27	-.03	.00	.05	.25	-.33	-.13	
Z	.15	.26	-.29	-.32	-.05	-.21	.16	-.21	-.20	-.12	-.15	.12	-.02

*z is the Target Area Mean for the transformed data; covariates $X_1, \ldots, X_{12}$ are defined in (3.1); Z is the seeding indicator variable with Z = 1 if seeding and Z = 0 if no seeding.

TABLE A-4(a): Analysis of Covariance Tables for Models (2) - (5), Transformed Data, for the Various Target Areas, Ground-Seeded Bands

Model	Source of Variation	d.f.	Mean Squares Target Areas (i)	(ii)	(iii)	(iv)	(viii)	F-Ratios Target Areas (i)	(ii)	(iii)	(iv)	(viii)
(2) Basic Six Covariates	Seeding	1	20.15	5.76	13.32	19.30	12.60	0.52	0.33	0.61	0.52	0.43
	Exp. Error	10	38.29	17.67	21.76	37.15	29.19	-	-	-	-	-
	Subtotal	11	36.64	16.59	20.99	35.53	27.68	-	-	-	-	-
	Covariates	6	28.74	10.76	17.10	26.51	22.36	2.16	1.91	1.99	1.98	2.85
	Sampl. Error	12	13.33	5.64	8.59	13.40	7.84	-	-	-	-	-
(3) Basic Covariates plus Duration	Seeding	1	58.14	13.53	39.22	57.30	30.78	1.94	1.03	2.16	1.96	1.34
	Exp. Error	10	29.91	13.09	18.13	29.19	22.96	-	-	-	-	-
	Subtotal	11	32.48	13.13	20.05	31.75	23.67	-	-	-	-	-
	Covariates	7	42.31	16.74	23.79	40.12	30.33	5.68**	3.47*	5.29**	5.48**	5.55**
	Sampl. Error	11	7.45	4.83	4.50	7.32	5.46	-	-	-	-	-
(4) Basic Covariates plus Control Area	Seeding	1	25.53	6.66	16.40	23.64	15.91	2.03	1.37	1.78	1.84	1.84
	Exp. Error	10	12.56	4.88	9.19	12.88	8.61	-	-	-	-	-
	Subtotal	11	13.74	5.04	9.85	13.86	9.27	-	-	-	-	-
	Covariates	7	74.47	30.93	40.89	70.56	54.66	13.00**	7.95**	10.70**	12.08**	12.51**
	Sampl. Error	11	5.73	3.89	3.82	5.84	4.37	-	-	-	-	-
(5) Basic Covariates plus Duration and Control Area	Seeding	1	27.42	4.41	19.71	26.77	14.72	2.19	0.88	2.16	2.08	1.73
	Exp. Error	10	12.52	5.01	9.11	12.84	8.49	-	-	-	-	-
	Subtotal	11	13.87	4.95	10.07	14.10	9.06	-	-	-	-	-
	Covariates	8	65.38	27.19	35.93	61.90	48.20	10.93**	6.35**	9.36**	10.27**	10.17**
	Sampl. Error	10	5.98	4.28	3.84	6.03	4.74	-	-	-	-	-

*Significant at 0.05 level.
**Significant at 0.01 level.

TABLE A-4(a) Continued: Analysis of Covariance Tables for Models (2) - (5), Transformed Data, for the Various Target Areas, Ground-Seeded Bands, Extreme Storm Omitted. [1]

Model	Source of Variation	d.f.	Mean Squares Target Areas					F-Ratios Target Areas				
			(i)	(ii)	(iii)	(iv)	(viii)	(i)	(ii)	(iii)	(iv)	(viii)
(2) Basic Six Covariates	Seeding	1	46.63	14.60	29.84	45.38	32.46	1.33	0.98	1.43	1.31	1.25
	Exp. Error	9	35.06	14.78	20.89	34.54	25.87	-	-	-	-	-
	Subtotal	10	36.22	14.76	21.79	35.63	26.53	-	-	-	-	-
	Covariates	6	8.77	3.20	6.65	8.57	7.34	0.61	0.60	0.67	0.58	0.90
	Sampl. Error	12	14.48	5.31	9.88	14.73	8.17	-	-	-	-	-
(3) Basic Covariates plus Duration	Seeding	1	98.77	24.88	66.69	98.36	57.23	3.53*	2.29	3.72*	3.55*	2.75
	Exp. Error	9	27.98	10.87	17.94	27.69	20.79	-	-	-	-	-
	Subtotal	10	35.05	12.27	22.82	34.76	24.43	-	-	-	-	-
	Covariates	7	21.21	8.36	13.02	21.11	14.30	2.61	1.87	2.51	2.61	2.50
	Sampl. Error	11	8.14	4.48	5.19	8.09	5.73	-	-	-	-	-
(4) Basic Covariates plus Control Area	Seeding	1	30.19	9.44	19.00	28.46	23.33	2.02	2.42	1.56	1.80	2.60
	Exp. Error	9	14.93	3.91	12.21	15.77	8.97	-	-	-	-	-
	Subtotal	10	16.46	4.46	12.89	17.04	10.41	-	-	-	-	-
	Covariates	7	50.70	20.92	28.38	48.96	36.11	8.08**	5.83**	6.40**	7.55**	7.85**
	Sampl. Error	11	6.27	3.59	4.44	6.49	4.60	-	-	-	-	-
(5) Basic Covariates plus Duration and Control Area	Seeding	1	28.97	5.13	21.54	29.18	17.89	1.93	1.24	1.77	1.84	1.98
	Exp. Error	9	14.98	4.15	12.17	15.82	9.04	-	-	-	-	-
	Subtotal	10	16.38	4.25	13.10	17.16	9.93	-	-	-	-	-
	Covariates	8	44.90	18.57	25.10	43.24	32.28	6.85**	4.71*	5.63**	6.45**	6.46**
	Sampl. Error	10	6.55	3.95	4.46	6.69	5.00	-	-	-	-	-

[1] One extreme precipitation storm, Storm 4 with one band, not seeded, has been omitted.
*Significant at 0.05 level; for seeding, the test is one-sided.
**Significant at 0.01 level.

TABLE A-4(b): Analysis of Covariance Tables for Models (2) and (3), Transformed Data, for the Various Target Areas, Aerial-Seeded Bands, Part I - All Bands

Model	Source of Variation	d.f.	Mean Squares					F-Ratios				
(2) Basic Six Covariates	Target Areas		(i)	(ii)	(iii)	(iv)	(v)	(i)	(ii)	(iii)	(iv)	(v)
	Seeding	1	45.14	26.29	15.76	39.15	5.56	0.97	1.61	0.56	0.89	0.51
	Exp. Error	28	46.65	16.35	28.02	44.03	10.90	-	-	-	-	-
	Subtotal	29	46.10	16.69	27.60	43.86	10.72	-	-	-	-	-
	Covariates	6	339.10	84.39	216.09	323.55	45.49	7.28**	5.77**	8.57**	7.93**	4.06**
	Sampl. Error	9	46.60	14.62	25.55	40.79	11.19	-	-	-	-	-
	Target Areas		(vi)	(vii)	(viii)	(ix)		(vi)	(vii)	(viii)	(ix)	
	Seeding	1	38.94	3.25	47.07	24.59		0.81	0.29	1.30	0.71	
	Exp. Error	28	48.02	11.38	36.32	34.61		-	-	-	-	
	Subtotal	29	47.71	11.10	36.69	34.27		-	-	-	-	
	Covariates	6	327.84	46.50	212.05	184.62		6.34**	4.12*	5.57*	5.08*	
	Sampl. Error	9	51.73	11.29	38.06	36.31		-	-	-	-	
(3) Basic Covariates plus Duration	Target Areas		(i)	(ii)	(iii)	(iv)	(v)	(i)	(ii)	(iii)	(iv)	(v)
	Seeding	1	27.61	21.20	7.90	24.07	3.22	0.58	1.30	0.28	0.54	0.30
	Exp. Error	28	47.63	16.27	28.68	44.91	10.87	-	-	-	-	-
	Subtotal	29	46.94	16.44	27.96	44.19	10.61	-	-	-	-	-
	Covariates	7	292.17	73.71	185.48	278.35	39.77	5.86*	4.57*	6.82**	6.35**	3.04
	Sampl. Error	8	49.88	16.14	27.19	43.81	13.06	-	-	-	-	-
	Target Areas		(vi)	(vii)	(viii)	(ix)		(vi)	(vii)	(viii)	(ix)	
	Seeding	1	23.18	1.42	31.57	14.42		0.48	0.13	0.86	0.42	
	Exp. Error	28	48.72	11.28	36.68	34.65		-	-	-	-	
	Subtotal	29	47.84	10.94	36.50	33.96		-	-	-	-	
	Covariates	7	283.04	40.96	184.71	161.29		5.06*	3.32	4.51*	4.10*	
	Sampl. Error	8	55.96	12.32	40.93	39.31		-	-	-	-	

*Significant at 0.05 level.
**Significant at 0.01 level.

TABLE A-4(b): Analysis of Covariance Tables for Models (2) and (3), Transformed Data, *for the Various Target Areas, Aerial-Seeded Bands, Part 2 - Mixed Storms Omitted*

Model	Source of Variation	d.f.	Mean Squares					F-Ratios				
(2) Basic Six Covariates	Target Areas		(i)	(ii)	(iii)	(iv)	(v)	(i)	(ii)	(iii)	(iv)	(v)
	Seeding	1	46.14	23.28	17.90	39.80	11.01	0.74	1.07	0.49	0.68	0.76
	Exp. Error	20	62.00	21.77	36.89	58.15	14.55	-	-	-	-	-
	Subtotal	21	61.24	21.85	35.99	57.27	14.38	-	-	-	-	-
	Covariates	6	248.74	57.65	161.91	238.31	35.00	4.82*	3.51	5.84*	5.31*	3.51
	Sampl. Error	7	51.63	16.45	27.73	44.92	9.98	-	-	-	-	-
	Target Areas		(vi)	(vii)	(viii)	(ix)		(vi)	(vii)	(viii)	(ix)	
	Seeding	1	48.96	8.48	35.79	30.58		0.75	0.57	0.74	0.66	
	Exp. Error	20	65.26	14.91	48.22	46.13		-	-	-	-	
	Subtotal	21	64.48	14.61	47.63	45.39		-	-	-	-	
	Covariates	6	240.72	34.83	152.68	133.40		4.49*	3.47	3.40	3.45	
	Sampl. Error	7	53.61	10.03	44.95	38.70		-	-	-	-	
(3) Basic Covariates plus Duration	Target Areas		(i)	(ii)	(iii)	(iv)	(v)	(i)	(ii)	(iii)	(iv)	(v)
	Seeding	1	3.52	7.21	0.23	3.19	0.57	0.05	0.31	0.01	0.05	0.04
	Exp. Error	20	68.71	23.24	40.68	64.03	15.84	-	-	-	-	-
	Subtotal	21	65.61	22.47	38.75	61.14	15.12	-	-	-	-	-
	Covariates	7	213.94	50.17	138.83	204.64	31.00	4.85*	3.10	6.14*	5.32*	3.91
	Sampl. Error	6	44.12	16.16	22.62.	38.45	7.92	-	-	-	-	-
	Target Areas		(vi)	(vii)	(viii)	(ix)		(vi)	(vii)	(viii)	(ix)	
	Seeding	1	3.17	0.19	3.66	1.81		0.05	0.01	0.07	0.04	
	Exp. Error	20	72.31	16.03	52.37	50.06		-	-	-	-	
	Subtotal	21	69.02	15.28	50.05	47.76		-	-	-	-	
	Covariates	7	207.71	31.05	132.86	116.78		4.61*	3.91	3.19	3.43	
	Sampl. Error	6	45.07	7.96	41.62	34.01		-	-	-	-	

*Significant at 0.05 level.
**Significant at 0.01 level.

TABLE A-5(a): Regression Coefficients for Model (5) for the Various Target Areas, Transformed Data, Ground-Seeded Bands

Covariates	Target Areas (i)	(ii)	(iii)	(iv)	(viii)
X_2 700 mb Spd.	-.0122	-.0453	-.0073	-.0147	-.0195
X_3 700 mb Wind Dir.	.0012	-.0160	.0046	.0011	-.0051
X_6 500 mb Temp.	-.1587	-.0570	-.1750	-.1621	-.1356
X_7 Stab. Class	-.1574	-.0218	-.1893	-.1578	-.0639
X_8 Showalter Index	-.0005	.0354	-.0110	-.0049	.0351
X_{11} Instab. Transpt.	.0002	-.0002	.0003	.0002	.0002
X_{12} Duration	.0816	-.0162	.1044	.0945	.0496
X_c Control Precip.	1.2495	1.7661	1.0567	1.2372	1.3062
Z Seeding	.5538	.4552	.5694	.5712	.5384

TABLE A-5(a) Continued: Regression Coefficients for Model (5) for the Various Target Areas, Transformed Data, Ground-Seeded Bands, Extreme Storm Omitted[1]

Covariates		Target Areas (i)	(ii)	(iii)	(iv)	(viii)
X_2	700 mb Spd.	-.0135	-.0426	-.0088	-.0163	-.0206
X_3	700 mb Wind Dir.	.0012	-.0151	.0048	.0011	-.0054
X_6	500 mb Temp.	-.1660	-.0565	-.1882	-.1704	-.1379
X_7	Stab. Class	-.1553	-.0280	-.1901	-.1554	-.0598
X_8	Showalter Index	-.0015	.0345	-.0134	-.0065	.0353
X_{11}	Instab. Transpt.	.0002	-.0001	.0003	.0002	.0002
X_{12}	Duration	.0848	-.0109	.1130	.0992	.0498
X_c	Control Precip.	1.2980	1.7193	1.1233	1.2907	1.3302
Z	Seeding	.5619	.4855	.5874	.5887	.5838

[1] One extreme precipitation storm, Storm 4 with one band, not seeded, has been omitted.

TABLE A-5(b): Regression Coefficients for Model (3) for the Various Target Areas, Transformed Data, Aerial-Seeded Bands, Part 1 - All Bands

Covariates	Target Areas (i)	(ii)	(iii)	(iv)	(v)
X_2 700 mb Spd.	.0997	.1301	.0903	.1034	.0561
X_3 700 mb Wind Dir.	-.0173	-.0132	-.0199	-.0188	-.0063
X_6 500 mb Temp.	-.0330	-.0616	-.0288	-.0359	.0514
X_7 Stab. Class	.2151	.2900	.1544	.1972	.1766
X_8 Showalter Index	-.0855	-.1037	-.0731	-.0829	-.0982
X_{11} Instab. Transpt.	.0018	.0021	.0017	.0019	.0014
X_{12} Duration	.4343	.3097	.4092	.4108	.2552
Z Seeding	.4209	.7491	.2760	.4125	.2570

	(vi)	(vii)	(viii)	(ix)
X_2 700 mb Spd.	.0816	.0470	.1222	.0744
X_3 700 mb Wind Dir.	-.0137	-.0073	-.0168	-.0112
X_6 500 mb Temp.	-.0105	.0550	-.0258	.0117
X_7 Stab. Class	.1946	.1684	.2449	.1936
X_8 Showalter Index	-.0865	-.0905	-.1024	-.0916
X_{11} Instab. Transpt.	.0016	.0012	.0021	.0015
X_{12} Duration	.3562	.2760	.5003	.3496
Z Seeding	.3365	.1562	.5926	.3119

TABLE A-5(b): Regression Coefficients for Model (3) for the Various Target Areas, Transformed Data, Aerial-Seeded Bands, Part 2 - Mixed Storms Omitted.

Covariates		Target Areas (i)	(ii)	(iii)	(iv)	(v)
X_2	700 mb Speed	.0871	.1234	.0884	.1004	.0545
X_3	700 mb Wind Dir.	-.0346	-.0297	-.0359	-.0354	-.0245
X_6	500 mb Temp.	-.0959	-.1473	-.0878	-.0995	-.0615
X_7	Stab. Class	.4968	.6319	.4172	.4816	.5186
X_8	Showalter Index	-.0052	-.0175	.0006	-.0041	-.0119
X_{11}	Instab. Transpt.	.0023	.0025	.0022	.0024	.0019
X_{12}	Duration	1.2131	1.1239	1.1278	1.1771	1.0218
Z	Seeding	.2115	.6154	.0660	.2099	.1501
		(vi)	(vii)	(viii)	(ix)	
X_2	700 mb Speed	.0793	.0450	.1195	.0722	
X_3	700 mb Wind Dir.	-.0304	-.0228	-.0354	-.0269	
X_6	500 mb Temp.	-.0879	-.0450	-.0715	-.0630	
X_7	Stab. Class	.4882	.4788	.5059	.4718	
X_8	Showalter Index	-.0078	-.0159	-.0187	-.0179	
X_{11}	Instab. Transpt.	.0020	.0016	.0028	.0019	
X_{12}	Duration	1.0973	.9433	1.3375	1.0429	
Z	Seeding	.1743	.0779	.2865	.1551	

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20. ABSTRACT

This report covers statistical analyses of the experimental data from Phase II of the Santa Barbara Convective Band Seeding Test Program conducted from 1970 to 1974. Comparisons are made with earlier analyses of the Phase I data.

The Phase II study was in two parts, essentially separate experiments, one using ground-seeding techniques and one using aerial-seeding techniques. Data summaries of both precipitation responses and potential concomitant variables are given in an appendix. The main analyses for examination of the effects of seeding are weighted analyses of variance of transformed precipitation data for various defined target areas in Section 5. The experiments are relatively small and no effects of seeding are apparent except for the aerial-seeded part of the experiment, when border-line one-sided significances are obtained after omission of four storms, not treated fully in accordance with the design plan. The use of concomitant variables as covariates in covariance analyses is examined, with tables given in the appendix. The use of covariates enhanced apparent treatment effects for the ground-seeded part of the experiment but not for the aerial-seeded part.

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20. ABSTRACT (Continued)

The Phase II study used storms as the basic experimental unit whereas the Phase I study used the convective band. Difficulties arise in analyses because of this change. The covariates were again measured in the area of expected response from seeding and hence are suspect. Improved design of future similar study would require use of better covariates, avoidance of possible seeding effects on the covariates, choice of good control areas, better selection of acceptable experimental units, the use of convective bands as experimental units, if possible persistence effects can be discounted, and the use of experimental designs that allow for storm effects as a source of variation.